Kansas Water Resources Research Institute Annual Technical Report FY 2010

Introduction

The Kansas Water Resources Institute (KWRI) is part of a national network of water resources research institutes in every state and territory of the U.S. established by law in the Water Resources Research Act of 1964. The network is funded by a combination of federal funds through the U.S. Department of the Interior/Geological Survey (USGS) and non-federal funds from state and other sources.

KWRI is administered by the Kansas Center for Agricultural Resources and the Environment (KCARE) at Kansas State University. An Administrative Council comprised of representatives from participating higher education or research institutions, state agencies, and federal agencies assists in policy making.

The mission of KWRI is to: 1) develop and support research on high priority water resource problems and objectives, as identified through the state water planning process; 2) facilitate effective communications among water resource professionals; and 3) foster the dissemination and application of research results.

We work towards this mission by: 1) providing and facilitating a communications network among professionals working on water resources research and education, through electronic means, newsletters, and conferences; and 2) supporting research and dissemination of results on high priority topics, as identified by the Kansas State Water Plan, through a competitive grants program.

Research Program Introduction

Our mission is partially accomplished through our competitive research program. We encourage the following through the research that we support: interdisciplinary approaches; interagency collaboration; scientific innovation; support of students and new young scientists; cost-effectiveness; relevance to present and future water resource issues/problems as identified by the State Water Plan; and dissemination and interpretation of results to appropriate audiences.

In implementing our research program, KWRI desires to: 1) be proactive rather that reactive in addressing water resource problems of the state; 2) involve the many water resources stakeholders in identifying and prioritizing the water resource research needs of the state; 3) foster collaboration among state agencies, federal agencies, and institutions of higher education in the state on water resource issues; 4) leverage additional financial support from state, private, and other federal sources; and 5) be recognized in Kansas as a major institution to go to for water resources research.

An Analysis of Sedimentation Reduction Strategies for Tuttle Creek Lake

Basic Information

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Principal Investigators:	Kyle R. Mankin

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2. Nejadhashemi, A.P., C.M. Smith, K.R. Mankin, R.M. Wilson, S.P. Brown, and J.C. Leatherman. 2009. Lower Little Blue Watershed Assessment: Preliminary Report. Kansas State Research and Extension Publication #EP-141. 61 pages. www.oznet.ksu.edu/library/h20ql2/EP141.pdf

An Analysis of Sedimentation Reduction Strategies for Tuttle Creek Lake

2008 - 2011 FINAL PROGRESS REPORT

Kansas Water Resources Competitive Grants Program

Principal Investigators and Institutional Affiliations:
Dr. Amirpouyan Nejadhashemi, Biosystems Engineering, Michigan State University
Mr. Craig Smith, Agricultural Economics, Kansas State University
Dr. Jeff Williams, Agricultural Economics, Kansas State University
Dr. Kyle Douglas-Mankin, Biological and Agricultural Engineering, Kansas State University
Dr. Bill Golden, Agricultural Economics, Kansas State University

Project duration: June 1, 2008 to May 31, 2011 (3 Years)

Keywords: Decision support system, Economic analysis, Sediment load, Watershed modeling.

Contents

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Sean Woznicki, Department of Biosystems and Agricultural Engineering Environmental Modeling Lab, Michigan State University

John Leatherman, Jeff Peterson, Josh Roe, and Robert Wilson Department of Agricultural Economics, Kansas State University

Dan Devlin and Sue Brown, Kansas Center for Agricultural Resources and the Environment (KCARE), Kansas State University

William Hargrove, Center for Environmental Resource Management, The University of Texas at El Paso

INTRODUCTION

With the primary purposes of flood control, electricity generation, water supply, and the creation of jobs, many water reservoir impoundments were built in the US from 1930-1960. As most reservoirs were produced by the construction of dams on rivers and streams, there was the obvious and inevitable realization that sediment deposition and accumulation would occur as the velocity of the waters approached zero. With this in mind, the majority of these structures were built to operate for a projected 50 to 200 years before various designated uses would be negatively impacted by excess sediment accumulation. For many of these reservoirs, the volume of water storage has been reduced by sedimentation. Sedimentation is the process by which sediment particles settle by gravity and deposit on the bottom of slow-moving waters. In some cases sediment accumulation has occurred slower than or on pace with projections, but in other cases sedimentation rates have greatly exceeded original estimates (Hargrove et al. 2010; Juracek 2007). Regardless of how closely actual rates match the original projections, the fact that 50 to 80 years have passed since dam closure on many US reservoirs indicates that reservoir sedimentation has and will become more of an environmental, social, and economic issue of concern going forward.

Erosion of cropland and streambanks have been identified as two culprits that not only cause significant damage to fields and lead to degraded aquatic ecosystems, but also result in sediment accumulations in downstream reservoirs. This poses environmental and economic concerns for stakeholders living in and around the watersheds and reservoirs affected by sedimentation. Sedimentation reduces reservoir storage capacity, negatively impacting public water supply, flood control capability, and water availability for downstream navigation. Both suspended and settled soil particles can affect the viability of aquatic life, reduce the recreational value of lakes and waterways, and increase operational costs to power plants, city water supplies, and navigation. Soil erosion also causes loss of cropland, particularly along stream and riverbanks, and lost soil productivity on crop and pasture land (Williams and Smith 2008).

FOCUS OF THIS RESEARCH

Reservoir sedimentation has been recognized as a major issue in much of the Midwestern US, including the state of Kansas. While there are many technical, environmental, and economic management problems associated with sediment sources and solutions to reservoir sedimentation, the state of Kansas has proactively recognized the need to protect, secure, and restore the life of its reservoirs (KWO 2010a). Because budgets are limited, every effort should be made to focus public and private funds to achieve the greatest return on the investment from soil erosion and sediment reduction strategies. This watershed modeling/economic analysis study provides an evaluation of a large watershed and reservoir severely impacted by erosion and sedimentation. The results from this study will be useful to stakeholders and decision-makers at the field, watershed, state, and national level.

This study focuses on the Tuttle Creek Lake (TCL) watershed located in northeast Kansas. In the 47 years that have passed since dam closure, TCL has lost over 42 percent of its total (multi-purpose and sediment) storage capacity due to sediment accumulation (KWO 2010b). TCL exhibits, perhaps, one of the most critical cases of reservoir sedimentation in

Kansas and throughout the Midwest. As of 2009, the Kansas Water Office estimated that the lake's sediment pool (Figure 1) had reached about 77 percent of design capacity (KWO 2010b).[1]

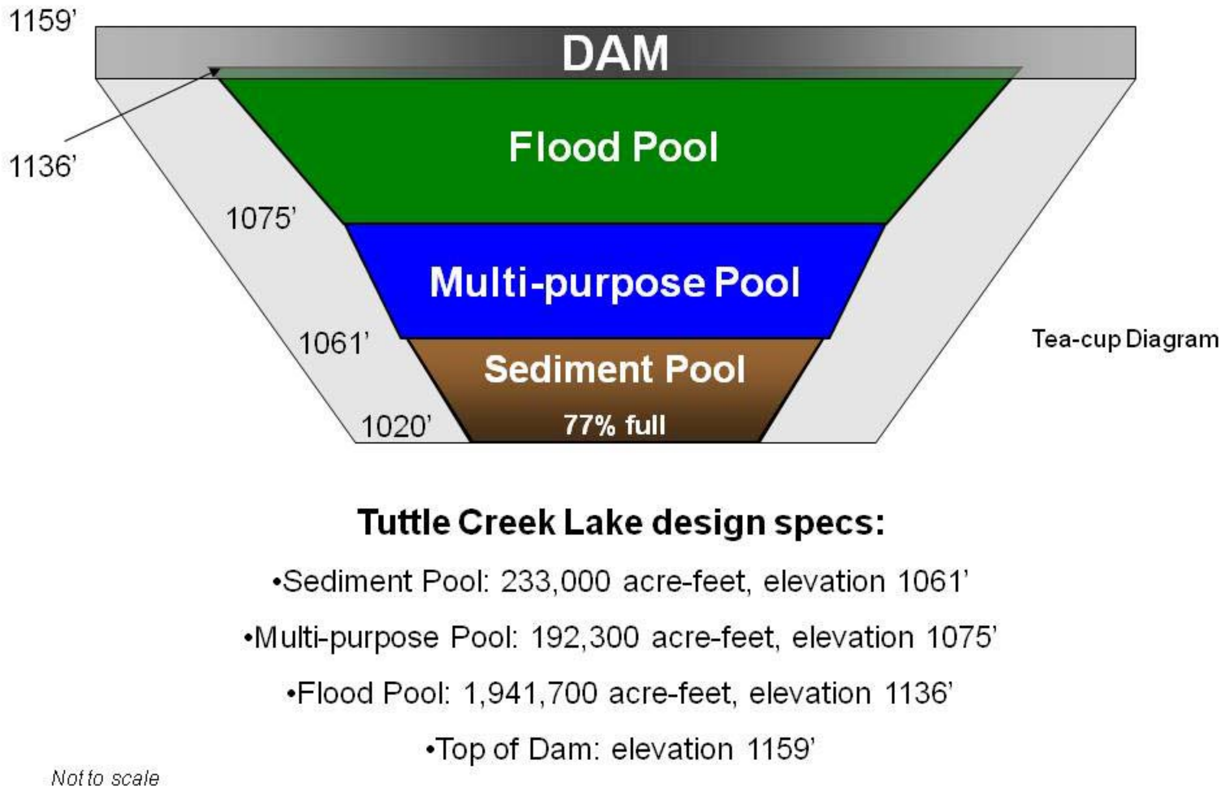

Figure 1 Reservoir design with Tuttle Creek Lake specifications

For several reasons, the loss of storage capacity and an overall degradation of reservoir quality are of importance to a variety of stakeholders. At the state level, the state of Kansas owns the rights to nearly 115,000 acre-feet (or nearly 60 percent of the multi-purpose pool) of water storage in TCL, which it uses for augmenting flows in the Kansas River to ensure adequate supplies of surface water for downstream industries and municipalities (e.g., Topeka, Lawrence, and the greater Kansas City area). The US Army Corps of Engineers holds the rights to the remaining water in the multi-purpose pool, which it uses for water quality and navigational purposes downstream, particularly in the Missouri River. The lake and surrounding parks also are important to the local economies. Smith and Leatherman (2008) estimated that TCL visitor expenditures generated $3.73 million (2007$) in direct economic activity (sales) within the regional (seven-county) economy, $1.74 million (2007$) in all types of income associated with the production of economic activities, and 82 area full- and part-time jobs. In another report, the US Army Corps of Engineers reported that the average annual economic benefits of TCL are $55 million (2000$) (USACE 2001). The breakdown given is $46.0 million in annual flood control benefits, $2.5 million in downstream navigation benefits, and $6.5 million in recreation and other

[1] In construction, a sediment pool is some fraction of the total storage capacity reserved for sediment accumulation. Once the sediment pool is 100 percent full, the lake still exists but additional accumulation reduces the multi-purpose pool storage. It is at this point that owners of water storage are negatively impacted (although one could argue that they are impacted well before this point is reached as well).

benefits. In 1993 alone, the damages prevented from flooding equaled $1.25 billion. Clearly, this lake and the surrounding park areas provide many valuable benefits to stakeholders.

Some of the above uses and activities will be negatively affected by poor water quality and/or sediment accumulation. In response to past and current water quality degradation, the lake has been listed on the state of Kansas's "303(d) list" for water quality impairment due to excessive levels of phosphorus, sulfate, pH, lead, biology, copper, and total suspended solids (EPA 2010).[2] Because of the importance of this resource, stakeholders from the national to the state to the local level have made the protection of TCL a priority.

To preserve and/or restore the reservoir and watershed, a reasonable approach may be to slow the trend of sediment accumulation. In order to do that, corrective action is needed and this action would ideally be based on a better understanding of watershed and stream sediment loading characteristics as well as the economic costs of alternative reservoir/watershed management strategies. How can physiographical and economic relationships within the watershed be quantified to provide insights into the selection of cost-effective alternative management strategies? This report focuses on answering that question by integrating a geographic information system (GIS) based watershed model, reservoir rehabilitation management strategies, statistical analyses of historic watershed and water quality data, with an economic analysis of alternative sedimentation reduction strategies. This will offer decision-makers better insight into the cost implications associated with achieving various water quality criteria and sedimentation reduction goals within a large watershed.

CONCEPTUAL FRAMEWORK

The conceptual framework can be divided into two parts. First, there is an underlying conceptual model for the best management practice (BMP) implementation scenarios on cropland within the watershed. The second part involves the concepts of dredging alongside or in place of BMP implementation. This conceptual framework section will be split into two subsections, which cover the two previously mentioned parts.

STAGE I: "BMP implementation" conceptual model description

Environmental protection within production agriculture often relies on incentives to induce adoption and implementation. The logic behind this is straightforward. Agricultural producers generally seek and adopt profit-enhancing practices and technologies on their own without compensation from outside sources. If a conservation BMP is profit-enhancing (benefits outweigh expected costs), producers will recognize this over time and choose to adopt the practice. One has to look no further than the increasing utilization of no-till over the past two decades. As for some other BMPs (e.g., filter strips), the producer may not receive any financial benefit from adoption. The benefits might go to stakeholders downstream and society in general. This is the definition of an externality. If a producer's goal is to maximize profit, there is often no incentive to adopt some BMPs.

Economic considerations are a key determinant in the adoption of BMPs. Although some producers have already adopted such practices, an expansion in adoption will occur only if the practices become profitable (in the absence of regulatory mandates). Simultaneously, it is important to recognize that producers across a watershed face different cost and production

[2] The term, "303(d) list," is short for the list of impaired waters that the Clean Water Act requires all states to submit for Environmental Protection Agency (EPA) approval every two years.

conditions. Although specific production practices may be profitable for some producers in some locations, they are not likely to be profitable for all producers in all locations. Further, the benefits of some BMPs accrue mostly to society at large and farmers may not be compensated for these external benefits. Federal, state, local agencies, and private organizations seek to provide incentives for environmental protection where markets have failed to do so (Claassen 2009). This analysis considers the financial costs that would have to be expended (e.g., from a governing authority) in order to entice producers to adopt a given set of BMPs across the watershed.

The underlying conceptual model may be best represented in flow-chart organizational form based on (but modified to fit this analysis) work by Vellidis et al. (2009). The conceptual model is shown in Figure 2. It shows the linkages among socioeconomic factors and producers' BMPs while explicitly integrating cause and effect among socioeconomic factors, producers' decision making, and physically-based outcomes. The entire model is constrained by a federal, state, and/or regional conservation program. That is, it is assumed that all profit-enhancing BMPs have been adopted at an earlier time and any additional BMP implementation will occur if and only if a conservation program (Box A) provides sufficient financial support. Within this program there is a suite of BMPs that can be adopted by producers. Physically-based and agronomic factors (Box B) as well as economic and social factors (Box C) determine whether or not BMPs will be adopted. Maintenance constraints (Box D) as well as physically-based and agronomic constraints (Box E) determine the effectiveness of the BMPs post-implementation. Further economic and social factors (Box F) can help to ensure that the BMPs remain in place throughout the life of the contract. A more detailed description of the six levels of the constraints is discussed in Smith (2011).

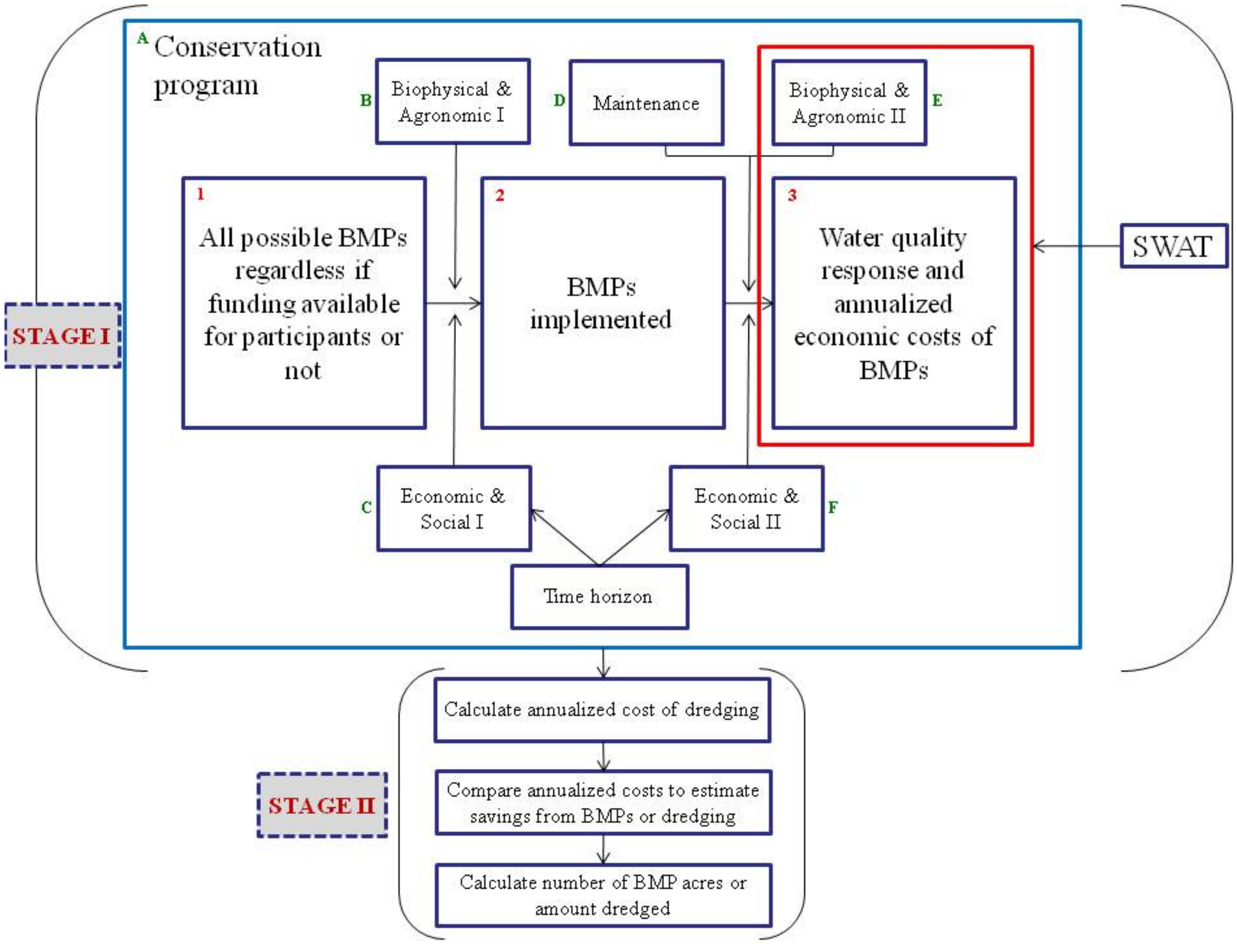

Figure 2 Conceptual model linkages and data flow within the integrated economic model

Figure 2 illustrates how the conceptual model is implemented. The Soil and Water Assessment Tool (SWAT) physically-based watershed model is used to evaluate the watershed's water quality response to the different BMP implementation scenarios. The amount of annual conservation payments needed to induce implementation of BMPs to different amounts of acreage is estimated based on partial budgeting as well as historical rental rates. This is described in detail in the "Data" section. The final results or outputs from this part of the analysis include amounts of pollutant reduction along with the annual total and marginal costs of BMP implementation. A more detailed description of these concepts follows.

Here, we consider the problem of a watershed manager who seeks to achieve maximum sediment reduction subject to an annual budget constraint. The individual costs of implementing a given BMP on a given cropland parcel are equal to the sum of the lost revenues and the additional costs incurred (both one-time and annual over a 15-year time horizon) for a given farm. Nonpecuniary benefits (e.g., wildlife enhancement) from BMP adoption may also be a consideration for some producers/landowners, but these are obviously difficult to quantify and are not included in this analysis. The annual aggregate cost of pollution reduction is represented by the sum of the annualized individual BMP implementation costs incurred.

To model the pollutant loading from each land parcel, a watershed model is developed. The model estimates edge-of-field loading and also factors in a delivery ratio to predict the average annual amount of pollutants entering the reservoir based on the application of BMPs

(Appendix A). Cost and load reduction factors are used for each BMP-farm combination to estimate individual cost-effectiveness values (e.g., dollars per ton of sediment reduction).

Two types of management strategies are modeled: targeted and random BMP implementation. The targeted approach implements BMPs on cropland that has the most attractive cost-effectiveness values (e.g., the lowest dollars per ton of sediment reduction). Implementation continues until the budget constraint is reached. The random approach models the case in which BMPs are implemented in a random fashion, which spreads the BMPs randomly across the watershed. This approach is possibly more akin to the status quo conservation programs in use currently across the country (although some targeting approaches are used in some programs).

Finally, total and marginal cost curves can be derived for pollutant reduction for each management strategy modeled. These costs can be compared to the marginal costs of dredging. From this, the "optimal" amount of sediment reduction achieved via BMP implementation and via dredging can be derived given the assumptions and constraints of the model.

STAGE II: "Dredging versus BMP implementation" conceptual model description

Along with BMP implementation, another method of reducing the amount of sediment in TCL is through dredging. While dredging may in fact also reduce the amount of nitrogen and phosphorus in the reservoir, analyzing these nutrient reductions with any precision would require knowledge of concentration levels in the dredged material. This is beyond the scope of this research and, thus, only sediment is considered in the "dredging versus BMP implementation" analysis.

Because sediment accumulation in TCL (and any reservoir for that matter) is inevitable, dredging is likely to be needed at some point in the future to preserve TCL. As it will be discussed later in this report, dredging can be a relatively expensive option. However, at some point it may become feasible if the costs of dredging are less than additional BMP implementation on a per unit basis of sediment reduction. The question is: at what point does this occur? This can be found by comparing the marginal costs of BMP implementation with the costs of dredging.

As Williams and Smith (2008) point out, the decision on whether or not to dredge will depend on sediment source, sedimentation rate with and without management practices, effectiveness and cost of management practices, dredging cost inflation, the planning horizon, and the discount rate used to calculate present values. If accumulated sediment has not negatively impacted current reservoir services (e.g., recreation, flood control), then it might be reasonable to forego dredging in favor of investing in additional in-field and in-stream conservation practices to reduce the need for future dredging.

Following Williams and Smith (2008), this analysis also examines how many acres a BMP can be applied to if savings generated from reduced dredging finance the implementation of the BMP. Estimated future savings from dredging costs avoided because of implementing sediment reduction BMPs are a key component of this analysis. To determine these values, the reservoir sedimentation rates are estimated with and without BMP implementation over a 15-year planning period. A 15-year period is chosen because this is approximately equal to the number of years until the sediment pool is 100 percent full given average annual sediment loading rates. The costs of dredging 15 years in the future also are estimated based on the current rate of sedimentation versus a reduced rate of sedimentation that will result from implementing BMPs. This analysis is limited to costs; therefore, any benefits resulting from reduced erosion, sedimentation, and/or any nutrient reduction that may occur are not considered here. The method used for comparing dredging with BMPs also is shown in Figure 2.

DATA

The data requirements for this study include both economic and physically-based data. This section begins by describing the types of BMPs considered and the economic costs (in 2009$) of each. The physically-based data for the simulations are generated from a calibrated watershed model. The second part of this section focuses on the model development and the physiographical results that are to be incorporated into the alternative watershed management simulations.

Best Management Practices

There are two main types of strategies for reducing the amount of sediment and nutrients that enter a reservoir: in-field and in-stream strategies. According to Devlin and Barnes (2008), in the Kansas River basin (which the Tuttle Creek watershed is a part of) unprotected croplands contributed the majority of sediment loads. While streambank erosion may contribute a significant amount of sediment to TCL, the watershed model developed here only considers the control of in-field sediment sources.[3] The three in-field strategies analyzed are filter strips, no-till, and permanent vegetation.

In general, it is likely that cropland BMPs have already been adopted by producers, who stand to reap significantly increased net returns from doing so. While there may be other producers who have the potential to benefit economically from adopting a given BMP, for whatever the reason, they may resist implementing that BMP. Additionally, there are likely many producers who would see decreased income by the adoption of certain BMPs. An assumption made for this study is that in order to induce any further BMP adoption within the Tuttle Creek watershed, cost-share and/or incentive payments would have to be made to producers. The next step is determining the level of costs (incentives) for inducing more BMP adoption for purposes of the simulation routines.

The details of BMP cost calculations are not covered in this report, but are available in Smith (2011). In general, 2009 data were used in the “original” scenarios and then were adjusted to represent higher cost values for BMPs in the TCL watershed. It is important to note that a 15-year time horizon is used for reasons stated earlier and a discount rate of 4.625 percent is used. This is based on the year 2009 “Plan Formulation Rate for Federal Water Projects” (NRCS 2009). Table 1 displays the annualized costs for each BMP by county in the TCL watershed for the “original” scenarios.

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[3] The Soil and Water Assessment Tool (SWAT) watershed model does not have the ability to analyze sediment and nutrient loading due to streambank erosion unless site specific data can be provided.

Table 1 "Original" BMP Annualized costs over a 15-year time horizon

County, State	Annualized Cost ($/acre) for Filter Strips per cropland acre treated[1]	Annualized Cost ($/acre) for No-till	Annualized Cost ($/acre) for Permanent Vegetation
Clay, KS	$3.83	$13.00	$81.05
Gage, NE	$5.67	$20.00	$108.15
Jefferson, NE	$5.67	$20.00	$101.93
Marshall, KS	$4.71	$13.00	$89.23
Nemaha, KS	$4.79	$13.00	$92.46
Pawnee, NE	$5.47	$20.00	$105.52
Pottawatomie, KS	$4.31	$13.00	$86.58
Republic, KS	$3.88	$13.00	$76.63
Riley, KS	$4.55	$13.00	$81.87
Washington, KS	$4.56	$13.00	$83.07

[1] Annualized cost of filter strip divided by 25 cropland acres ("treated")

Physically-based Model and Results

This subsection presents the physically-based model that quantifies the environmental impacts of practices adopted by farmers in the mostly Kansas portion of the watershed. In particular, the SWAT model is applied to the Tuttle Creek watershed located in Kansas and Nebraska to predict the changes in sediment loading at the watershed outlet (entering TCL), in response to the adoption of the three cropland in-field BMPs.[4] The first part briefly describes the study region and the input data for the SWAT model. The next part presents the modeling scenarios, which correspond to the three BMPs of interest plus a baseline (no BMPs) situation. Each scenario requires detailed inputs about tillage and other agronomic practices. The third part then presents the modeling results from the various scenarios and explains how the data needed for the simulations are assembled. The fourth and final part briefly summarizes the model and results. A more detailed description of the model setup and calibration process can be found in Appendix A.

Model Inputs

A necessary component of an effective BMP implementation plan is a way to estimate the amount of pollution reduction achieved from the adoption of certain BMPs. In order to analyze the potential of various BMP management scenarios in the Tuttle Creek watershed, a SWAT watershed model was developed for the portion of the Tuttle Creek watershed located almost completely in Kansas (Figure 3). It should be noted that the sediment contributions from the greater Nebraska portion of the watershed were included in the analysis, but treated as exogenous in the models. In other words, no BMP applications occurred in the greater Nebraska portion of the TCL watershed.

[4] As described later, BMP implementation only occurs in the "Kansas" portion of the watershed. The word "Kansas" is in quotes because very small portions of the analyzed subwatersheds actually lie in Jefferson, Gage, and Pawnee counties located in Nebraska.

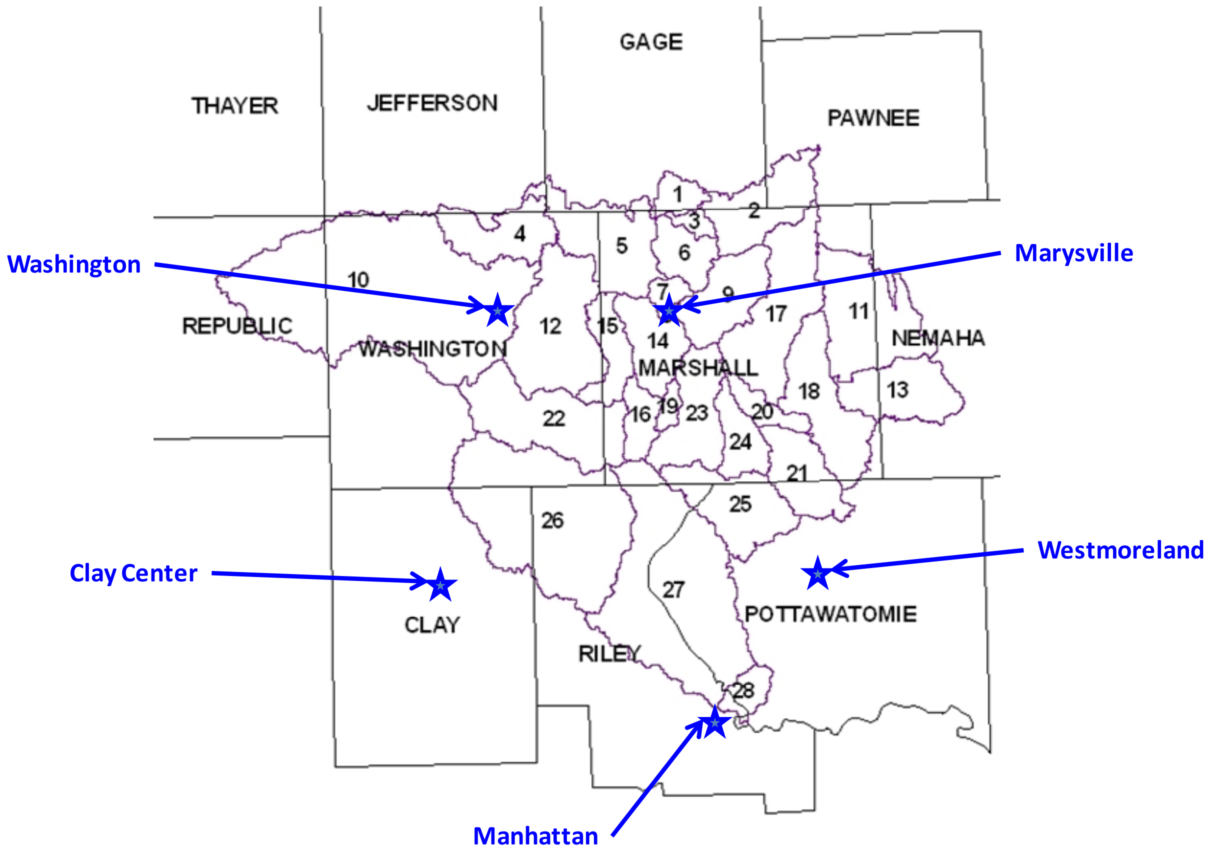

Figure 3 Kansas portion of the Tuttle Creek watershed with subwatershed delineation

The SWAT (2009) model was developed and is maintained by the USDA Agricultural Research Service (ARS) (Arnold et al. 1998; Neitsch et al. 2005; Gassman et al. 2007; Douglas-Mankin et al. 2010). SWAT is a watershed-scale model widely used for quantifying the impact of land management practices (Nejadhashemi et al. 2011; Rodriguez et al. 2011). Briefly, the SWAT model was developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large complex watersheds with varying soils, land-use, and management conditions over long periods of time. Major model components include weather, hydrology, soil temperature, plant growth, nutrients, pesticide, and land management (Gassman et al. 2007). Each watershed is divided into subwatersheds and then into hydrologic response units (HRUs) based on land-use, slope, and soil distributions.

A preliminary step in the watershed model development process was to access reliable landuse data. The most recent comprehensive land use data set available was the National Land Cover Data (NLCD) created and compiled by the United States Geological Survey in 2001.

In addition to the 2001 NLCD landuse data, other physically-based data were acquired for use in the SWAT model. State Soil Geographic Database (STATSGO) soils data was incorporated into the model along with 31 years of relevant National Oceanic and Atmospheric Administration (NOAA) weather data. A summary of the land use, slope, and hydrologic soil groups located in each of the 28 subwatersheds are displayed in Table 2.

Table 2 Summary of land use, slope, and soil group by subwatershed

		Land Use (%)						Slope (%)					Hydrologic Soil Group (%)			
Sub-watershed	Area (ac)	Crop	Urban	Forest	Range	Wet-land	Water	0-2	2-4	4-6	6-8	8+	A	B	C	D
1	12,393	44.5	4.6	8.4	41.1	0.0	1.4	76.1	18.6	4.3	1.0	0.0	0.0	16.2	83.8	0.0
2	48,527	63.5	3.8	4.9	27.2	0.0	0.6	79.5	17.6	2.9	0.0	0.0	0.0	1.5	0.0	98.5
3	6,267	57.1	4.7	12.3	22.9	0.0	3.0	76.5	19.5	4.0	0.0	0.0	0.0	20.5	33.9	45.6
4	39,374	36.4	2.9	7.5	51.4	0.4	1.3	62.9	25.3	9.3	2.2	0.3	0.0	41.2	55.2	3.6
5	60,724	58.8	4.4	6.6	29.6	0.3	0.4	75.4	19.4	4.6	0.6	0.0	0.0	4.3	95.7	0.0
6	23,890	67.0	4.4	6.2	20.0	0.7	1.7	73.6	24.1	2.3	0.0	0.0	0.0	16.2	40.4	43.4
7	7,734	50.8	11.4	6.5	26.2	2.3	2.8	78.2	20.5	1.4	0.0	0.0	0.0	26.5	40.6	32.9
8	1,450	39.1	12.6	0.0	39.4	0.0	8.9	100.0	0.0	0.0	0.0	0.0	0.0	49.7	0.0	50.3
9	42,852	68.6	5.8	5.2	19.5	0.4	0.6	78.0	17.7	3.6	0.7	0.0	0.0	1.0	0.0	99.0
10	259,609	43.1	4.4	6.0	45.8	0.1	0.5	67.3	21.4	8.4	2.7	0.3	0.0	34.8	63.2	1.8
11	75,604	72.2	4.4	3.9	19.0	0.0	0.6	66.4	24.8	7.7	1.1	0.0	0.0	3.3	0.0	96.7
12	81,114	41.1	4.1	5.8	46.3	1.1	1.7	63.2	23.2	10.7	2.7	0.2	0.0	19.5	60.6	19.9
13	45,102	50.7	4.7	6.9	35.9	0.0	1.9	61.5	23.7	12.3	2.5	0.0	0.0	6.5	0.0	93.5
14	34,557	42.2	4.7	8.9	40.2	2.1	1.9	57.7	22.5	12.6	5.0	2.1	0.0	14.1	46.2	39.7
15	26,028	52.6	4.2	7.6	34.0	0.7	0.9	60.4	27.7	9.9	2.1	0.0	0.0	6.8	78.5	14.7
16	17,768	40.8	6.7	8.2	41.5	1.0	1.8	63.7	22.5	10.2	3.0	0.6	0.0	17.3	41.9	40.8
17	75,559	58.3	4.6	7.2	28.8	0.5	0.6	62.9	25.9	9.4	1.8	0.0	0.0	7.7	0.0	92.3
18	59,506	40.3	4.4	10.1	43.5	0.7	1.0	56.5	26.5	13.7	3.1	0.2	0.0	7.1	0.0	92.9
19	6,183	16.8	11.3	7.4	57.9	3.5	3.1	58.6	16.7	12.7	7.1	5.0	0.0	26.0	24.4	49.6
20	14,667	40.3	3.8	10.3	44.0	1.5	0.0	63.3	25.2	10.3	1.2	0.0	0.0	12.7	0.0	87.3
21	38,499	20.2	4.0	9.7	65.5	0.3	0.3	54.0	26.5	14.1	4.9	0.5	0.0	0.3	42.1	57.6
22	76,565	44.6	4.0	6.1	44.8	0.2	0.3	67.9	22.1	7.8	2.1	0.1	0.0	4.8	63.1	32.1
23	45,733	38.0	3.6	8.7	47.0	1.4	1.3	56.7	23.3	14.5	4.9	0.6	0.0	15.3	18.9	65.8
24	23,823	24.7	2.9	10.5	59.3	1.0	1.5	57.8	20.9	14.1	5.9	1.4	0.0	18.6	33.4	48.0
25	53,826	8.5	2.5	12.0	74.2	1.8	1.1	49.1	19.5	17.2	9.7	4.6	0.0	7.2	62.2	30.6
26	160,864	33.6	3.7	5.8	56.3	0.2	0.3	59.4	26.0	10.5	3.1	1.0	0.0	14.2	47.8	38.0
27	169,764	8.7	4.3	16.6	59.4	1.2	9.7	44.4	18.6	16.7	11.2	9.1	0.0	12.0	69.4	18.7

The entire Tuttle Creek watershed area is 6,144,000 acres, with 25 percent of the entire watershed area residing in Kansas. According to data compiled from the 2007 National Agricultural Statistics Service (NASS) reports, the average farm size in the watershed was 482 acres with a size distribution depicted in Figure 4. The median sized farm in the watershed was calculated from the NASS data to be approximately 243 acres. In order to delineate a watershed to fit the NASS results while maintaining reasonable shape and size for hydrology, the Kansas portion of the Tuttle Creek watershed was divided into 27 subwatersheds.[5] Subwatersheds were further divided into 2,752 hydrologic response units (HRUs) which are unique combinations of land use and soil that occur within an individual subwatershed. Within these 2,752 HRUs, only 1,858 were categorized as cropland.

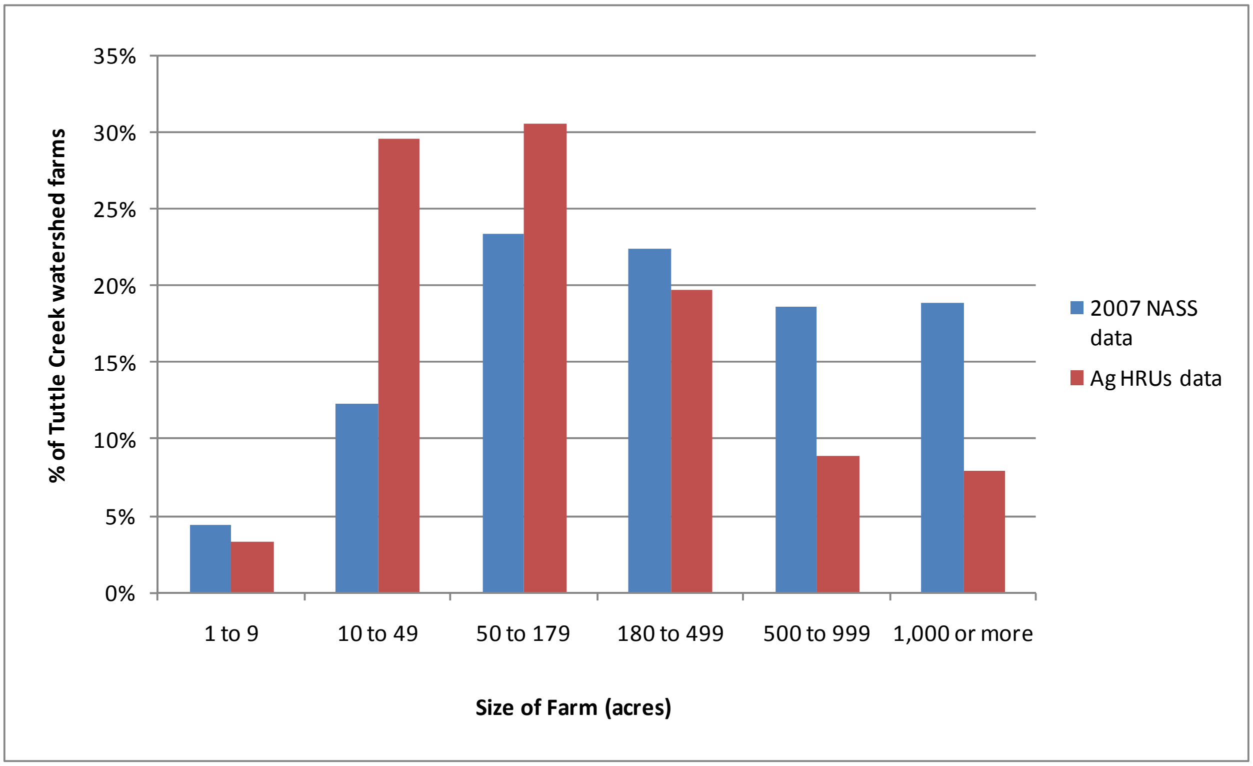

Figure 4 Size distribution of farms in the Tuttle Creek watershed

Focusing on the 1,858 agricultural HRUs, the average size was 350 acres with the smallest being 5 acres and the largest being approximately 8,175 acres in size. The median size for the HRUs was 107 acres. About 60 percent of the HRUs were between 10 and 179 acres while nearly 80 percent were sized between 10 and 499 acres. The size distribution of the agricultural HRUs followed somewhat closely to the NASS derived distribution of farms as shown in Figure 4. The HRU data consisted of many farms in the 10 to 179 acre range which resulted in a slightly smaller average farm size than the NASS data. The median values of 107 acres and 243 acres for the HRUs and the NASS data, respectively, again supported the fact of there being many “smaller” sized farms.

[5] Actually, the TCL watershed was divided into 28 subwatersheds (Figure 4) which was necessary to calculate loading into TCL. However, subwatershed 28 is located on the backside of the dam and does not contribute any loading to the reservoir. For this reason, the results only include loading from subwatersheds 1 through 27.

Modeling Scenarios

Based on previous research and reports (Williams et al. 2009; Langemeier and Nelson 2006; O'Brien and Duncan 2008a-d), data for cropping rotations and the associated field operations were developed for the Kansas and Nebraska portions of the Tuttle Creek watershed. For the Kansas side, there were four major crops planted and harvested under six different cropping rotations. For the Nebraska side, there were four major crops occurring under three different cropping rotations. Having knowledge of predominant crop rotations and knowing the reported crop acreage from the NASS, the proportions of each cropping rotation were estimated for each state-side of the TCL watershed. The crop acreage was very near the reported crop acreage reported by the NASS. Table 3 shows the crop and rotation breakdown for each state side of the watershed. It was assumed that these crop rotations existed in the TCL over the 31 year SWAT modeling simulation period.

Table 3 Percentage of crops and rotations in the TCL watershed

Kansas side of TCL watershed		**Nebraska side of TCL watershed**	
Crop	**Percentage of Cropland**	**Crop**	**Percentage of Cropland**
Corn (C)	37%	Corn (C)	63%
Grain Sorghum (G)	29%	Grain Sorghum (G)	3%
Soybeans (S)	28%	Soybeans (S)	31%
Wheat (W)	7%	Wheat (W)	3%
Cropping Rotation		**Cropping Rotation**	
C-S	25%	C-S	55%
Continuous S	5%	Continuous C	35%
Continuous C	15%	G-S-W	10%
S-W	25%		
Continuous W	10%		
G-S-W	20%		

In addition to the cropping rotations, the associated field operations and enterprise budgets also were developed. Examples of the field operations used for a continuous corn cropping rotation are shown in Table 4. The remaining field operations by cropping rotation and enterprise budgets can be found in Smith (2011).[6]

[6] The field operations data were used in the SWAT watershed model. The enterprise budget data were not directly utilized to calculate BMP costs, but can be provided for additional information.

Table 4 Continuous corn rotation under conventional tillage

Date	Practice	SWAT Practice	Amount
3/27	Tandem disk	Tandem disk plow	
4/5	Chisel	Chisel plow	
4/5	Knife anhydrous ammonia	Anhydrous ammonia	116 lbs/ac
4/15	Field cultivate	Field cultivator	
4/15	Herbicide application	Atrazine	1.9 lbs/ac
4/15	Herbicide application	Metolachlor	1.5 lbs/ac
4/16	Plant corn	Plant/Begin growing season	
4/16	Nitrogen application	Elemental nitrogen	14 lbs/ac
4/16	Phosphorus application	Elemental phosphorus	47 lbs/ac
5/20	Herbicide application	Dicamba	0.3 lbs/ac
10/1	Harvest corn	Harvest and kill	
11/5	Chisel	Coulter Chisel plow	

Under the baseline scenario, the crops (and thus, cropping rotations) were randomly applied throughout the watershed consistent with the data displayed in Table 3. The cropland was rotated in a manner consistent with the data in Table 3 throughout the course of the 31 years of weather simulation in the SWAT model. In the baseline case, it was assumed that there were no filter strips in place and all cropland was farmed using conventional tillage as shown in Table 5.

Table 5 Description of scenarios

	Baseline	Scenario #1	Scenario #2	Scenario #3
Tillage System	Conventional	Conventional	No-till	N/A
Filter Strip?	NO	YES	NO	N/A
Types of crops	Cropping	Cropping	Cropping	Native grass

In scenario 1, the cropland also was under conventional tillage. However, this scenario included a 33 ft wide grass filter strip at the edge of each cropland HRU. It is assumed that each acre of filter strip treats runoff from 25 acres of cropland. Note, that the edge of each HRU does not necessarily border a body of surface water, hence each filter strip does not necessarily border a body of surface water. The cropping rotations were the same as in the baseline scenario (Table 5).

Scenario 2 employed 100 percent no-till management on all cropland. The only operations that break the surface of the ground are planting and drilling in a 100 percent no-till system. Chemicals are used for weed control. There were no filter strips in place and the cropping rotations were the same as in the baseline scenario (Table 5).

Scenario 3 involved converting all cropland into native grass (Table 5). The native grass permanent vegetation (land retirement) was a mixture of bluestem grasses, switchgrass, and

Indiangrass. Once established, there was no cultivation involved with the permanent vegetation, and it was assumed that there would be no fertilization.

Modeling Results and Findings

As described previously, scenarios 1, 2, and 3 assume BMP application across all cropland HRUs in the Kansas portion of the TCL watershed. While it is not realistic to assume that all cropland in the watershed will be treated by a BMP simultaneously, we move forward with the assumption that the estimated HRU pollutant loading values maintain their relative rankings and any inaccuracies in loading predictions are negligible. This assumption allows us to utilize the SWAT analysis output (ex-post) as input into the economic models.

The average sediment loading estimates across all cropland HRUs is displayed by Table 6 along with percentage reductions in pollutant loading from the baseline for all three BMP scenarios.

Table 6 Acre-weighted average sediment loading at edge of HRU across all agricultural HRUs (tons/ac/yr)

Pollutant	**Baseline**	**Filter Strips**	**100% No-till**	**Permanent Veg.**
	Average loading at edge of HRU (tons/acre/year)			
Sediment	2.87	0.78	2.21	0.15
	Percentage loading reduction from baseline (%)			
Sediment	-	72.6%	23.0%	94.6%

Focusing on the loading at the edge of the agricultural HRUs, the average sediment loading under the baseline condition was estimated to be just below 2.9 tons/ac/yr. When 33 feet wide native grass filter strips were applied to all agricultural HRUs, the watershed-wide average sediment loading was reduced by 72.6 percent (Table 6) to 0.78 tons/ac/yr.

The use of 100 percent no-till management applied to all cropland fields resulted in lesser sediment reduction than filter strips by reducing loadings by 23 percent across the watershed. When all of the cropland in the watershed was converted to a permanent stand of native grass, substantial reductions in sediment loading resulted. Sediment loading was reduced by approximately 95 percent.

To account for sediment transport in the watershed, delivery ratios are typically derived for each subwatershed and for each HRU. The delivery ratio of pollutant loading is a function of the stream transport effects. The stream transporting effects are defined as the outflow pollutant load divided by the inflow load. The difference between inflow and outflow loads are due to pollutant deposition or other losses. The sediment delivery ratios tend to be slightly variable across subwatersheds as displayed in Table 7. A delivery ratio of 0.56 in subwatershed 1 indicates that on average every one ton of sediment (leaving the edge of an HRU located in that subwatershed) results in 0.56 tons in TCL. The remaining 0.44 tons is assumed to be deposited within to the stream channel. In general, the subwatersheds located nearer TCL and/or a major tributary exhibit higher sediment delivery ratio values.

Table 7 Sediment delivery ratios by subwatershed

Subwatershed	Sediment Delivery Ratio
1	0.56
2	0.51
3	0.56
4	0.71
5	0.67
6	0.60
7	0.68
8	0.69
9	0.70
10	1.00
11	0.69
12	1.00
13	0.66
14	0.73
15	1.00
16	0.99
17	0.72
18	0.67
19	1.00
20	0.75
21	0.79
22	1.00
23	1.00
24	0.79
25	1.00
26	1.00
27	1.00

ECONOMIC SIMULATION MODEL

The simulation model developed for this research constitutes the primary piece of the full decision support system. The simulation model is developed in MATLAB, which is a matrix based, numerical computing environment used for simulation, data management, econometrics, and statistics. The model developed is built specifically for the TCL watershed. However, it could be modified for application in other agricultural-based watersheds given that the necessary physiographical and economic data is made available. The computer code for both a targeted and a random scenario is provided in Appendix B.

Using output from the SWAT watershed model as input, the economic analysis model simulates possible BMP implementation scenarios, and estimates the resulting pollutant loading into a reservoir and the costs of implementing the BMPs. There are two versions of the economic analysis model. The first emulates an economically optimal BMP scenario where BMPs are placed in areas of the watershed where pollutant loading is reduced at the lowest cost. The other version emulates a random approach to BMP implementation in the watershed. This to some degree represents the status quo approach of uniform BMP implementation across a watershed and serves as a point of comparison for the economically optimal approach. Both of these models operate under the criteria of meeting a specified pollutant reduction goal subject to a specified budget constraint. These models can focus on either sediment, nitrogen, or phosphorus reduction individually and can accommodate up to three different types of BMPs.[7]

Considering the multitude of social, environmental, economic, and political factors present at any point in time in an agricultural watershed, attempting to effectively examine the cost-effectiveness of alternative watershed management schemes can be a difficult task. An increasingly popular method of analyzing complex systems is the utilization of agent-based simulation modeling. An agent-based model (ABM) is a class of computational models with agents representing autonomous decision-making units. This allows the analyst to assess the effects of agent decision-making on the system as a whole. Recently, ABM's have become a popular model choice for analyzing complex systems driven by micro-level decisions (Tesfatsion 2006). ABM's are particularly useful in emulating alternative market structures, specifically those where agents are heterogeneous and adapt their behavior to institutional rules.

ABM's are made up of two computational objects: the "agents" themselves and the "environment" in which they operate (Parker, Berger, and Manson 2002). In the Tuttle Creek watershed, the agents are the farm managers and the environment is the management mechanism that determines which BMPs are implemented and where. A goal of the simulations is to understand how changes in the environment (management mechanism) may induce different patterns and levels of BMP adoption among the agents.

Agents

The $I = 1{,}858$ farms (HRUs) are indexed by $i = 1, \dots, I$ and are considered potential BMP adopters and thus have the ability to reduce the amount of soil leaving their cropland fields. It is assumed that a governing authority has set a goal of reducing the maximum amount of sediment, S units, entering TCL while operating under an annual fiscal budget of D dollars per year. Each farm can generate up to s_i units of sediment reduction at a total annualized cost of c_i. Using the cost of implementing each BMP data described previously, total costs, which include one-time and annual costs over a given time horizon for each BMP on each farm, are determined and assigned. The average per unit costs of pollutant reduction (dollars per pound of pollutant reduced) are calculated for each farm-BMP combination. Average per unit costs are assumed to vary across farms but are constant at the farm level. This cost property implies that the aggregate total and marginal cost curves will have "staircase" structures.

[7] For this study, only sediment is considered as the primary pollutant of concern.

Each farm can potentially adopt one of B BMPs, $b = 1, \ldots, B$ where $B = 3$. The three BMPs are filter strips, no-till, and permanent vegetation. Let **A** denote the (I x B) "average per unit cost matrix" representing the per-unit costs for BMP implementation by farm (HRU). If farm *i* is to adopt a given BMP, a_{ib} must be positive. That is, the BMP implemented must result in a positive amount of sediment reduction if sediment is the primary pollutant of concern. Before any BMP implementation occurred, the program eliminates any farm-BMP combination which displays negative pollutant reduction[8] ($a_{ib} < 0$) because it is assumed that rational managers of these farms would not elect to adopt BMPs that actually increased the amount of pollutant runoff.

An assumption of the SWAT model is that there are no BMPs in place in the Base scenario. First-hand knowledge of the area as well as NRCS reports indicate that this is not the case. But, the challenge is to determine where BMPs have been put into place and where they exist today. Determining this with any precision and incorporating this into the SWAT model is a difficult and expensive task that is beyond the scope of this research. For that reason, the following method is used.

While personal knowledge and NRCS reports show that many soil saving BMPs have been implemented over the past three decades, other research has determined that some farmers have extremely high willingness to accept (WTA) values and will most likely need high payments for adoption and will not adopt certain BMPs under most realistic scenarios (Smith et al. 2007). To account for these facts, it is assumed that 25 percent of the farms either had already adopted BMPs or had extremely high WTA values for BMP adoption. In either case, it is assumed that farms with these characteristics would not adopt new or additional BMPs in the model's time horizon studied.

At the beginning of each BMP implementation simulation, 25 percent of the farms (465 total) are eliminated from the potential pool. Again, the problem is determining which 465 out of the 1,858 farms would be eliminated. To handle this, the 465 ineligible farms are picked in a random fashion each time and Monte Carlo techniques are used with 3,000 iterations.

Once these initialization search and delete methods are completed, the simulation program proceeds to the selection process for BMP implementation (note, each of the 3,000 iterations consists of the initialization processes and BMP implementation routine).

Environment

The "environment" is the management mechanism that determines which BMPs are implemented on which farms in the watershed and the order in which these occur. The mechanism used is similar to a method used in the modeling of water quality trading markets. Specifically, the method modeled is a variant of the sequential, bilateral trading algorithm proposed by Atkinson and Tietenberg (1991).

The BMP implementation process occurs by iterating over BMP implementation projects in the sequence they occur. With each implementation project, indexed by *t*, the algorithm begins by identifying the particular farm-BMP combination (*i*,*b*). Two different ways of doing this are

[8] This is only for the objective pollutant (or pollutant of concern); not all three pollutants.

modeled, one which simulates a highly targeted approach and the other which is random and more representative of a worst-case, potentially status-quo approach. These two implementation regimes are described below.

Once the farm-BMP combination is identified, a BMP is implemented resulting in q_t units of sediment reduction. This quantity is recorded, along with the average annualized per unit cost of sediment reduction, a_{ib}, total cost, $q_t a_{ib}$, and area treated by the BMP for each farm. The **A** matrix is then updated by eliminating that farm (setting $a_{i|} = 0$) from further BMP implementation because of the restriction of one BMP implemented per farm. The model then iterates through additional BMP implementation projects using the same process until: 1) no positive values exist in the **A** matrix; 2) no other BMPs could be implemented without violating the budget constraint; or 3) the sediment reduction goal has been met.

The two implementation regimes are:

1. Targeted BMP implementation: This scenario assumes full information in that BMPs can be placed strategically in the watershed to deliver the greatest sediment reduction for least cost. In this optimal case, the algorithm determines the farm-BMP combination (a_{ib}) which has the lowest (and positive) average per unit cost of sediment reduction. If this combination will not exceed either the pollutant reduction goal or the budget constraint, then the BMP will be implemented on this farm and the resulting pollutant reduction and cost will be recorded in an output matrix as described above. This farm will then be removed from the possible choice set which prevents it from being selected again.
2. Random BMP implementation: The random approach to BMP implementation assumes very low information and occurs in much of the same fashion as the optimal approach with one very important distinction. That is, each farm-BMP combination (a_{ib}) is selected in a completely random manner in which no consideration is given to the average per unit costs of pollutant reduction assuming neither of the constraints will be violated.

Scenarios Modeled

Each of the BMP implementation scenarios operate under varying budget constraints. The annual budget constraint varies from $50,000 to $450,000 per year in increments of $100,000. These values are in line with estimated minimum and maximum funding amounts that could be available from the state of Kansas (e.g., through WRAPS and Kansas Water Plan funding sources) for purposes of addressing sedimentation in the TCL watershed (KDHE 2009). Table 8 lists the assumptions for each of the 10 simulation scenarios modeled. These are modeled using both the “original” and adjusted “Y” BMP cost scenarios.

Table 8 Description of scenarios

Scenario	BMP Regime	Primary Pollutant	Annual Budget
Targ_S_50	Targeted	Sediment	$50,000
Targ_S_150	Targeted	Sediment	$150,000

Targ_S_250	Targeted	Sediment	$250,000
Targ_S_350	Targeted	Sediment	$350,000
Targ_S_450	Targeted	Sediment	$450,000
Rand_S_50	Random	Sediment	$50,000
Rand_S_150	Random	Sediment	$150,000
Rand_S_250	Random	Sediment	$250,000
Rand_S_350	Random	Sediment	$350,000
Rand_S_450	Random	Sediment	$450,000

BMP IMPLEMENTATION RESULTS

This section begins by summarizing the overall simulation results followed by more in depth analyses regarding the effects of targeting versus random BMP implementation strategies, budgetary constraint levels, and changing BMP costs.

Table 9 summarizes the results of the original 10 scenarios. The first column serves as a cross reference for the scenario assumptions listed in Table 8. The second column reports the average sediment reduction costs per unit. The next four columns report information related to BMP projects implemented in terms of the description of the projects and the total amount of land treated by the BMPs.[9] Columns six through eight of this table provide more detail regarding the categories of the BMP projects in terms of the number of filter strips, no-till, and permanent vegetation projects, respectively. Column nine reports the total amount of land area treated by the BMP projects. The final column of Table 9 reports the total amount of sediment reduction achieved by the implementation of the BMP projects.

Overall the lowest overall average annual cost of sediment reduction is achieved by the Targ_S_50 scenario which reduces sediment for $0.35 per ton. The highest cost per ton of sediment is with the Rand_S_450 scenario at $14.13 per ton. This is only slightly higher than the Rand_N_450 and Rand_P_450 scenarios which are $13.88 and $13.47 per ton, respectively

Table 9 Original simulation results

Scenario	Average sediment reduction cost for all land treated by BMPs (/ton)	Total # of BMP projects	# of Filter Strip Projects	# of No-till Projects	#of Permanent Vegetation Projects	Total area of land treated by BMPs (ac)	Total amount of sediment reduction (tons)
Targ_S_50	$0.35	84	84	0	0	10,578	139,488
Targ_S_150	$0.47	249	249	0	0	32,118	314,587
Targ_S_250	$0.55	327	327	0	0	53,640	447,431
Targ_S_350	$0.62	415	415	0	0	74,970	553,999
Targ_S_450	$0.69	502	502	0	0	96,494	640,157
Rand_S_50	$7.65	20	9	7	4	3,009	6,317
Rand_S_150	$10.95	33	14	11	8	6,604	13,169

[9] In the cases of no-till and permanent vegetation, one acre of BMP application “treats” one acre of cropland. However, in the case of filter strips, one acre of filter strip is assumed to “treat” runoff from 25 acres of cropland.

Rand_S_250	$12.44	44	17	15	12	9,800	19,291
Rand_S_350	$13.45	53	20	18	15	12,630	24,838
Rand_S_450	$14.13	62	23	21	18	15,522	30,332

The number of BMP projects range from a low of 20 in all of the random implementation scenarios operating under a $50,000 annual budget to a high of 502 BMPs in the Targ_S_450 scenario.

The total area of land treated by BMPs ranges from 3,009 acres in the Rand_S_50 scenario up to 96,494 acres in the Targ_S_450 scenario. Across all of the budget constraints, the targeted scenarios affect more land than the corresponding random scenarios. For example, there is 96,494 acres treated by BMPs in the Targ_S_450 scenario but only 15,522 acres are treated in the Rand_S_450 scenario. The greatest amount of annual sediment reduction is achieved by the Targ_S_450 scenario at 640,157 tons.

Targeting vs. Random BMP Implementation

Targeting should, by definition, result in more cost-effective primary pollutant reduction than random BMP implementation. This is found to be the case in the TCL watershed. Targeted sediment strategies range from approximately 20.5 to over 23.2 times more cost-effective than random implementation strategies in terms of sediment reduction.

Targeted strategies result in a greater number of BMP projects and a larger number of acres treated by the projects relative to the random approaches. Not only does targeting require more effort up front in terms of watershed modeling, but it also requires more BMP contracts and/or meetings with producers.

Figure 5 displays the total cost curves for the targeted versus random schemes focusing on sediment with a $50,000 annual budget. Across the entire range of values, the total cost curve for the targeted strategy is much flatter than the random case. The flatness of the total cost curve indicates that more sediment is being reduced at the same total cost. Given a $50,000 annual budget, the targeted strategy reduces over 22 times more sediment compared to the random case. Alternatively, if the goal is 6,300 tons of sediment reduction it would cost nearly $50,000 to achieve this through random approaches versus just $1,600 using a targeted strategy which is 3.2 percent of the cost.

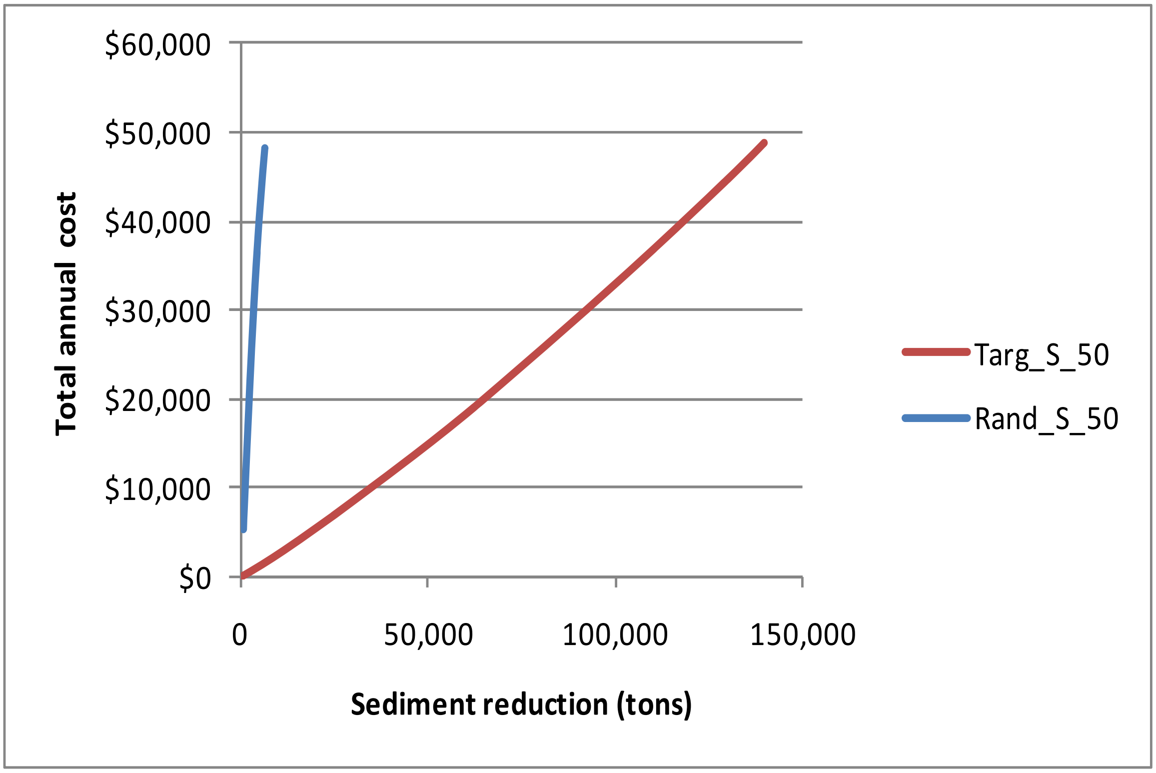

Figure 5 Sediment total cost curves for Targ_S_50 and Rand_S_50

The total cost curve data in Figure 5 can also be expressed marginally. That is, how does the average annual cost per ton change as more sediment is being reduced? Examining the marginal cost curves in Figure 6 for these same scenarios highlights more of the differences between strategies. The random approach yields a downward sloping somewhat variable marginal cost curve. This curve ranges from $10.00 to $5.00 per ton marginal cost values. The targeted strategy, on the other hand, is upward sloping climbing from $0.22 to $0.44 per ton of sediment reduction.

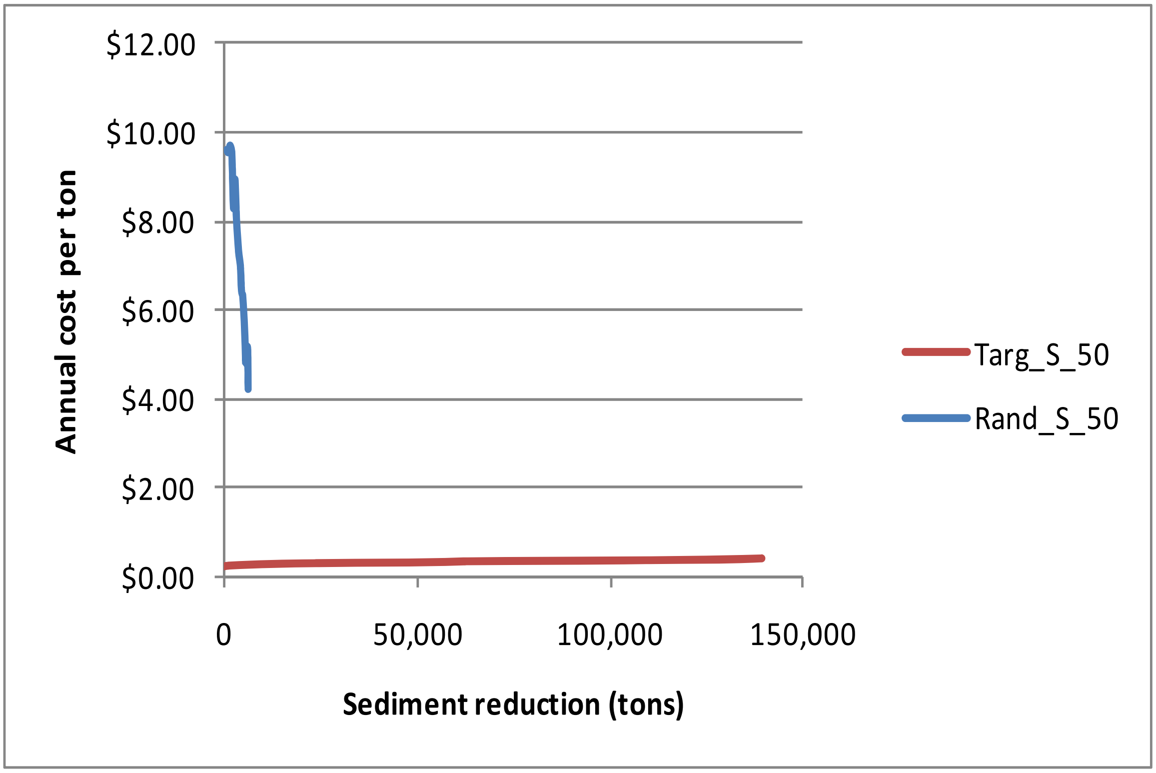

Figure 6 Sediment marginal cost curves for Targ_S_50 and Rand_S_50

Effects of the budget constraint

As the budget increases from $50,000 to $450,000, the total cost curve for the targeted case continues increasing at an increasing rate. This means that the primary pollutant reduction becomes more expensive as the most cost-effective BMPs are implemented. Thus, the marginal cost curve for the targeted case should continue to be upward sloping as the budget constraint increases.

Figure 7 shows how the total cost curve for the $150,000 case essentially builds upon the total cost curve for the $50,000 scenario. This continues as the budget constraint increases. However, upon closer inspection one can see that there is not a perfectly smooth transition between like scenarios with different budget constraints. Figure 8 shows that total cost curve for the lower budget constraint scenario deviates above the higher budget scenario as the budget constraint is approached. This is because “large” total cost projects which may be the next best in terms of cost-effectiveness may exceed the budget. Thus, lower total cost projects must be implemented even though they may not be the next best in terms of cost-effectiveness. This result occurs in each of the targeted scenarios as budget constraints change.

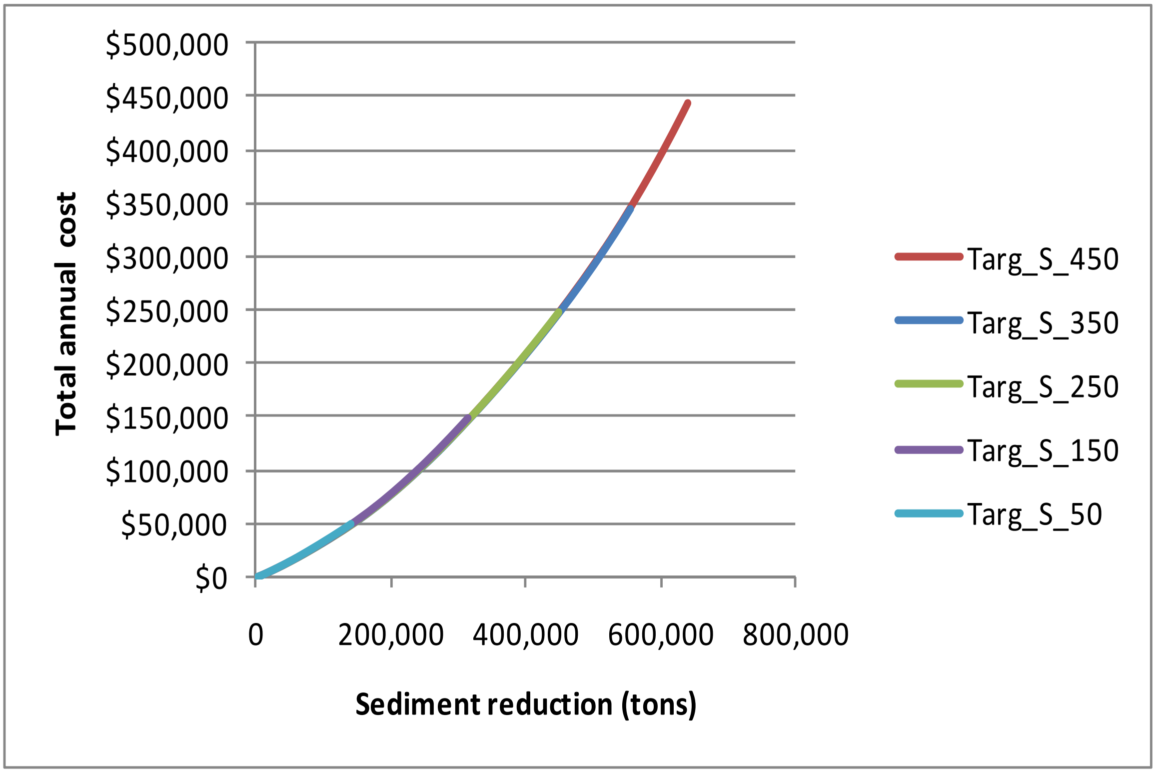

Figure 7 Sediment total cost curves for Targ_S scenarios

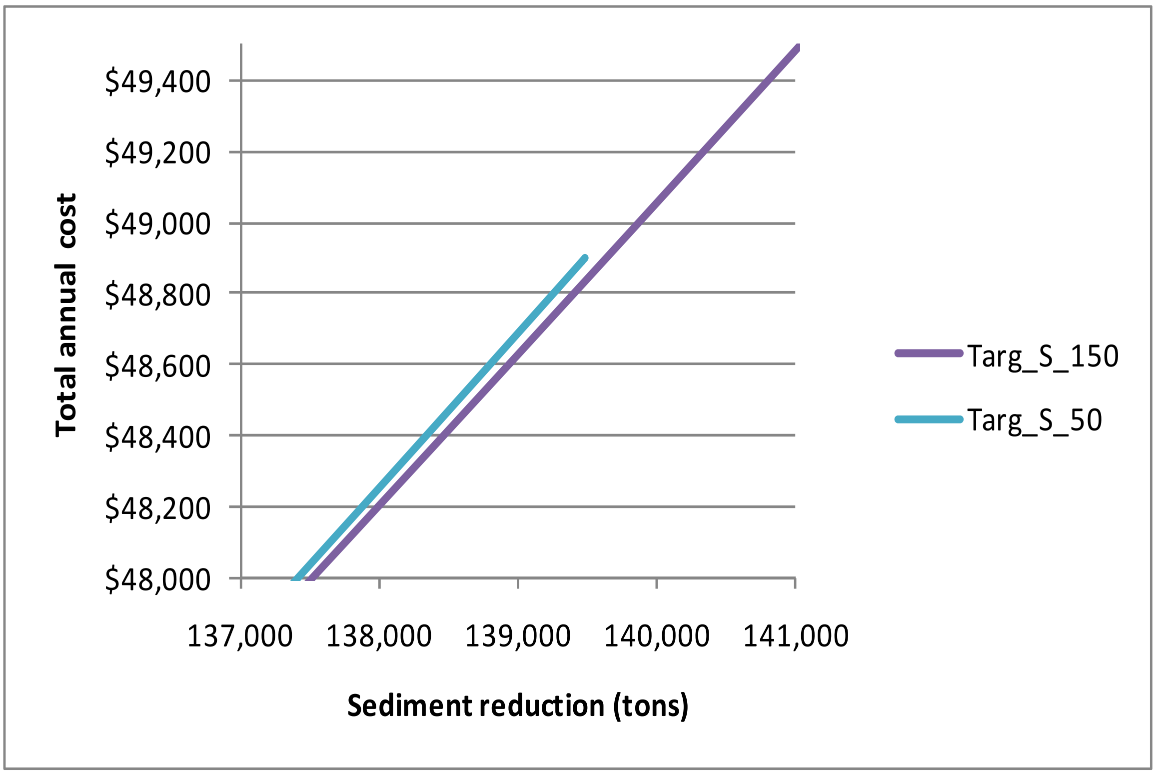

Figure 8 Sediment total cost curves for Targ_S_50 and Targ_S_150

This result also is seen by analyzing the marginal cost curves. In Figure 9, the marginal cost curves are upward sloping and essentially build upon each other. In each scenario, the marginal cost curve turns nearly vertical as the budget constraint is reached. However, there is very little horizontal movement at those points, so the effects on total costs are minimal.

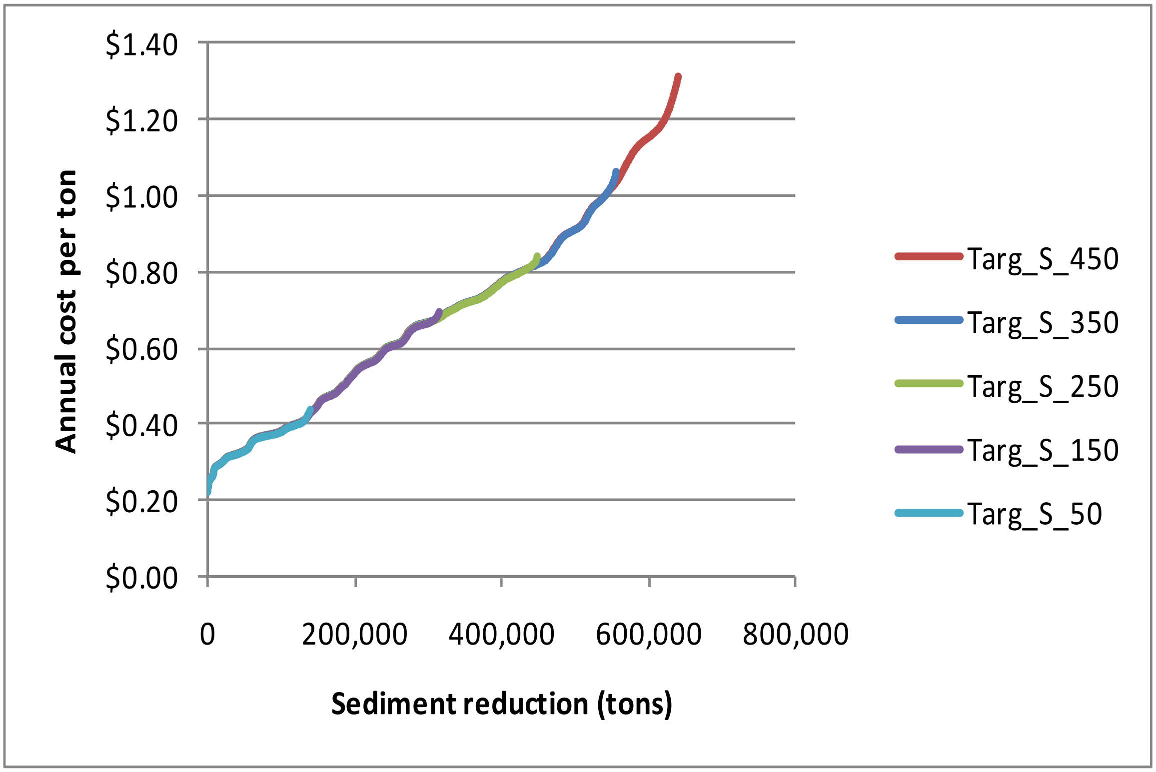

Figure 9 Sediment marginal cost curves for Targ_S scenarios

The marginal cost curves for the random scenarios do not build upon each other as the budget constraint increases. The average marginal cost of sediment reduction steadily increases from $7.65 to $14.13 per ton as the budget increases from $50,000 to $450,000 per year (Table 9). Figure 10 shows that the marginal cost curve for Rand_S_50 lies entirely below the other curves across the first 6,300 tons of sediment reduction. Apparently, there are some rather "large" total cost projects with high average sediment reduction costs that cannot be implemented because the budget constraint would be violated. As the budget constraint increases these high cost projects are feasible to be implemented. This is seen by looking at the marginal cost curves for Rand_S_150, Rand_S_250, Rand_S_350, and Rand_S_450 scenarios in Figure 10.

The reasons for the downward sloping trends of the curves in Figure 10 are related to the budget constraints. As the budget constraint is approached, many of the high average cost projects cannot be implemented for reasons stated previously. Thus, "lower" average cost projects ("lower" relative to the projects that would be implemented without the imposition of a budget constraint) are implemented causing the marginal cost curve to trend downwards. This point is illustrated by looking that the first 5,000 tons of reduction in Figure 10 for the relatively high budget scenarios, Rand_S_350 and Rand_S_450 and in the case of an infinite budget constraint shown later in Figure 11. The larger budget constraint scenarios generate somewhat flatter marginal cost curves (Figure 10).

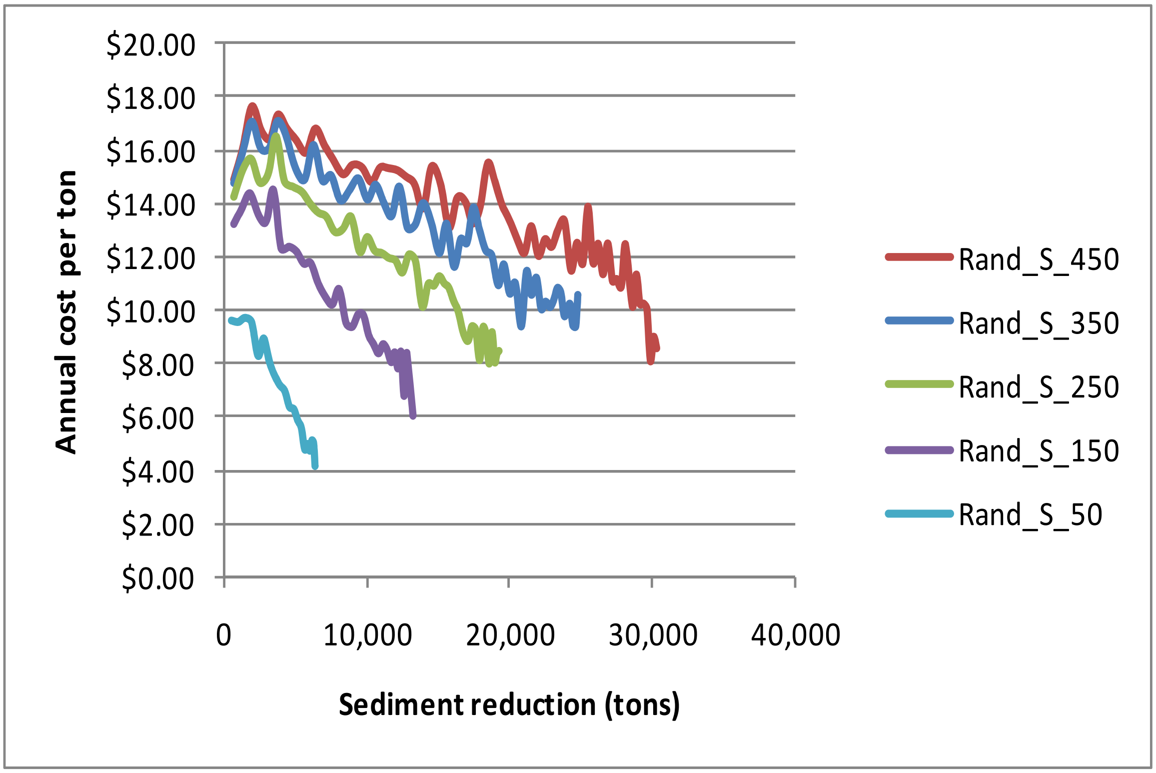

Figure 10 Sediment marginal cost curves for Rand_S scenarios

For purposes of illustration (and not realism), each of the targeted and random scenarios are run under an unlimited budget constraint and pollutant reduction goal. The results for these scenarios are displayed in Table 10. Under an unlimited budget scenario, the targeted approaches are approximately 8.5 times more cost effective than the random scenarios. Figure 11 shows the marginal cost curves for the target and random approaches for sediment.

At first glance, it may appear odd that the targeted curve rises above the random curve after approximately 850,000 tons of sediment reduction in Figure 11. The reason for this is that the last few BMP projects implemented in the targeted scenario have very high average costs (i.e., the last six projects have average costs of greater than $100 per ton of sediment reduction). These are relatively small projects as evidenced by the lack of rightward horizontal movement of the Targ_S_$$$ curve. The average typical cost of sediment reduction achieved through random implementation is approximately $32.49 from the first to the last ton of reduction.

Table 10 Simulation results for the targeted and random scenarios with an unlimited budget and pollutant reduction goal

Scenario	Total annual cost of BMPs	Average S reduction cost for all land treated by BMPs (/ton)	Total # of BMP projects	# of Filter Strip Projects	# of No-till Projects	#of Perma-nent Vegeta-tion Projects	Total area of land treated by BMPs (ac)	Total annual amount of S reduction (tons)
Targ_S_$$$	$3,429,944	$3.89	1,393	815	578	0	484,551	880,609
Rand_S_$$$	$30,230,696	$32.49	1,393	464	464	465	484,607	930,535

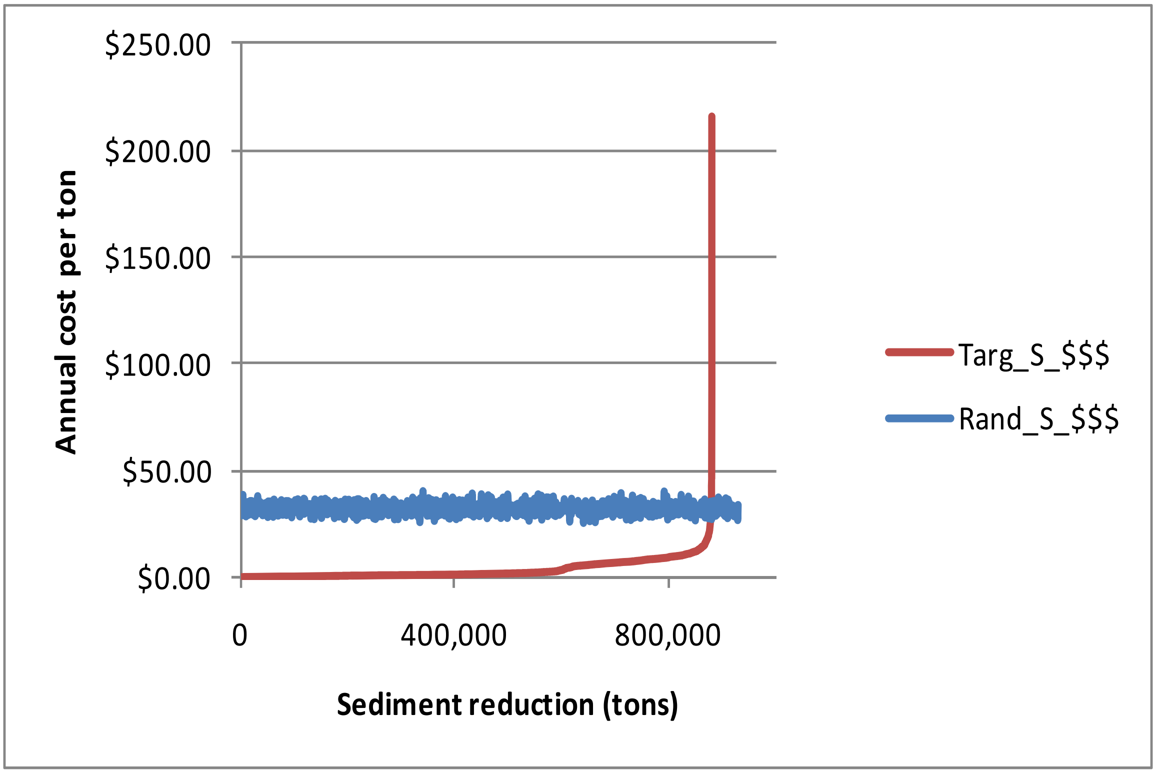

Figure 11 Sediment marginal cost curves under an unlimited budget constraint

Effects of changing BMP costs

The BMP cost data displayed in Table 1 are based on 2009 values of cropland cash rent, CRP rents, and establishment and maintenance costs for filter strips and for converting cropland to permanent vegetation.[10] Further, the costs of no-till are based on per acre incentive payments for converting to no-till established by the EQIP program in 2009 (KS EQIP 2009; NE EQIP 2009).

Recent upward swings in commodity prices and overall farm profitability are being capitalized into land values and rents. Thus, the opportunity costs associated with converting cropland to filter strips and permanent vegetation also increase. Increasing fuel prices also result in higher establishment costs for each of these BMPs. Meanwhile, higher fuel prices make no-till

[10] Comprehensive budgets for filter strips and permanent vegetation can be found in Smith (2011).

a more financially attractive option (all else being equal) to conventional or minimum tillage. For these reasons, adjustments to the 2009 BMP costs are made as follows for the "X" and "Y" scenarios. Note, that no tabular data or results are presented for the "X" scenarios due to space limitations.[11]

For the "Y" scenarios, the total annualized costs for filter strips and permanent vegetation are increased by 200 percent to capture a more drastic increase in land opportunity costs and fuel prices. For no-till, the annualized costs were decreased by 75 percent to account for the even higher fuel prices, and thus, a greater relative cost advantage of no-till (all else equal).

Table 11 displays the annualized costs for each BMP over a 15-year time horizon. These scenarios will be denoted as the "Y" scenarios to distinguish these from the original and "X" scenarios.

Table 11 Adjusted BMP Annualized costs over a 15-year time horizon - "Y" scenarios

County, State	Annualized Cost ($/acre) for Filter Strips per cropland acre treated[1]	Annualized Cost ($/acre) for No-till	Annualized Cost ($/acre) for Permanent Vegetation
Clay, KS	$7.66	$3.25	$162.10
Gage, NE	$11.34	$5.00	$216.30
Jefferson, NE	$11.34	$5.00	$203.86
Marshall, KS	$9.41	$3.25	$178.46
Nemaha, KS	$9.57	$3.25	$184.92
Pawnee, NE	$10.95	$5.00	$211.04
Pottawatomie, KS	$8.63	$3.25	$173.16
Republic, KS	$7.76	$3.25	$153.26
Riley, KS	$9.10	$3.25	$163.74
Washington, KS	$9.11	$3.25	$166.14

[1] Annualized cost of filter strip divided by 25 cropland acres (treated)

Table 12 displays the results of the "Y" scenarios. In general, the results for the "Y" scenarios follow the same patterns as the original and "X" scenarios. In all cases the amount of pollutant reduction achieved by the "Y" scenarios is less than the corresponding original and "X" scenarios. A notable difference here is that in the targeted "Y" scenarios, both filter strips and no-till are implemented in each of the budget constraints considered.

[11] The 'X' scenarios are where annualized filter strips and permanent vegetation costs are increased by 150 percent and no-till costs are decreased by 50 percent. Results for these scenarios can be found in Smith (2011).

Table 12 Simulation results for the "Y" scenarios

Scenario	Average sediment reduction cost (/ton)	Total # of BMP projects	# of Filter Strip Projects	# of No-till Projects	#of Permanent Vegetation Projects	Total area of land treated by BMPs (ac)	Total amount of sediment reduction (tons)
Targ_S_50_Y	$0.63	62	32	30	0	7,297	79,092
Targ_S_150_Y	$0.78	181	107	75	0	22,255	189,131
Targ_S_250_Y	$0.92	266	165	101	0	36,695	270,298
Targ_S_350_Y	$1.02	311	198	113	0	48,945	340,221
Targ_S_450_Y	$1.11	359	228	131	0	61,382	401,990
Rand_S_50_Y	$8.39	21	8	10	3	3,375	5,774
Rand_S_150_Y	$13.02	32	12	14	7	6,328	11,147
Rand_S_250_Y	$15.77	40	14	17	9	8,458	15,321
Rand_S_350_Y	$17.99	46	16	19	11	10,228	18,720
Rand_S_450_Y	$19.53	52	18	21	13	11,945	22,181

Figure 12 and Figure 13 display the marginal and total cost curves for sediment, respectively, as the costs of BMPs change from the original case to the "X" case and finally to the "Y" case. Across the first 100,000 tons of sediment reduction, each of the marginal cost curves appear to have similar slopes (only different y-intercepts). However, after 100,000 tons of reduction, the slope of scenario "Y" increases at a much faster rate than the original scenario.

Figure 14 depicts the total acreage being treated by BMPs across total sediment reduction for each of the different scenarios. It can be seen that the curves for the original and "X" scenarios perfectly overlay across the first 503,000 tons of reduction. From this figure, it is evident that the original and "X" scenarios consist of the same 426 BMP projects. In each of these scenarios, only filter strips are applied. Because filter strip costs are higher in the Targ_S_450_X scenario, the acreage-sediment reduction curve ends after when the $450,000 constraint is met at 503,000 tons of reduction.

The Targ_S_450_Y scenario, on the other hand, follows closely to the original and "X" scenario curve across the first 100,000 tons of reduction. It is likely that the same filter strips are being applied in each case. After 100,000 tons of reduction, no-till becomes the most cost-effective BMP and more of these projects are implemented in the "Y" scenario. However, no-till is not as environmentally effective on a per acre basis as filter strips. So, more acres need to be treated to achieve the same amount of sediment reduction as compared to the other two scenarios. In the "Y" scenario, 350,000 tons of sediment reduction requires 50,500 acres of BMP treatment, whereas, only 37,500 acres need to be treated in the "X" scenario to achieve a similar reduction.

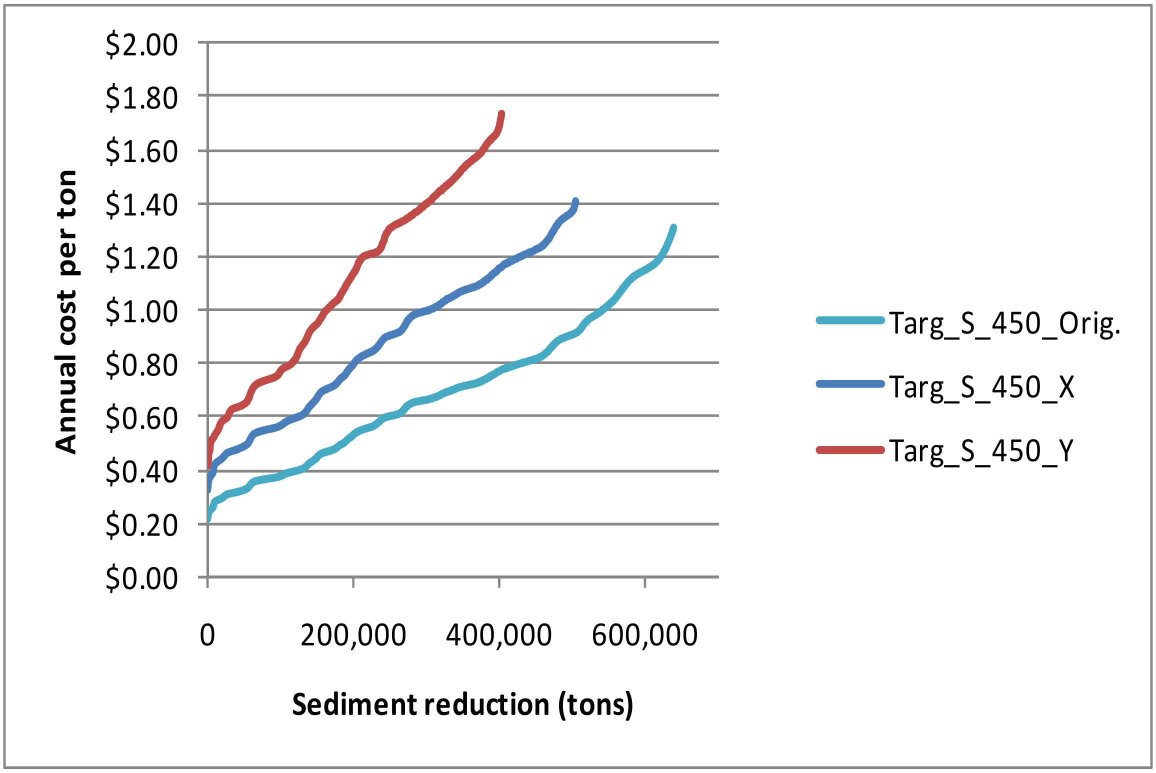

Figure 12 Sediment marginal cost curves for different BMP cost levels

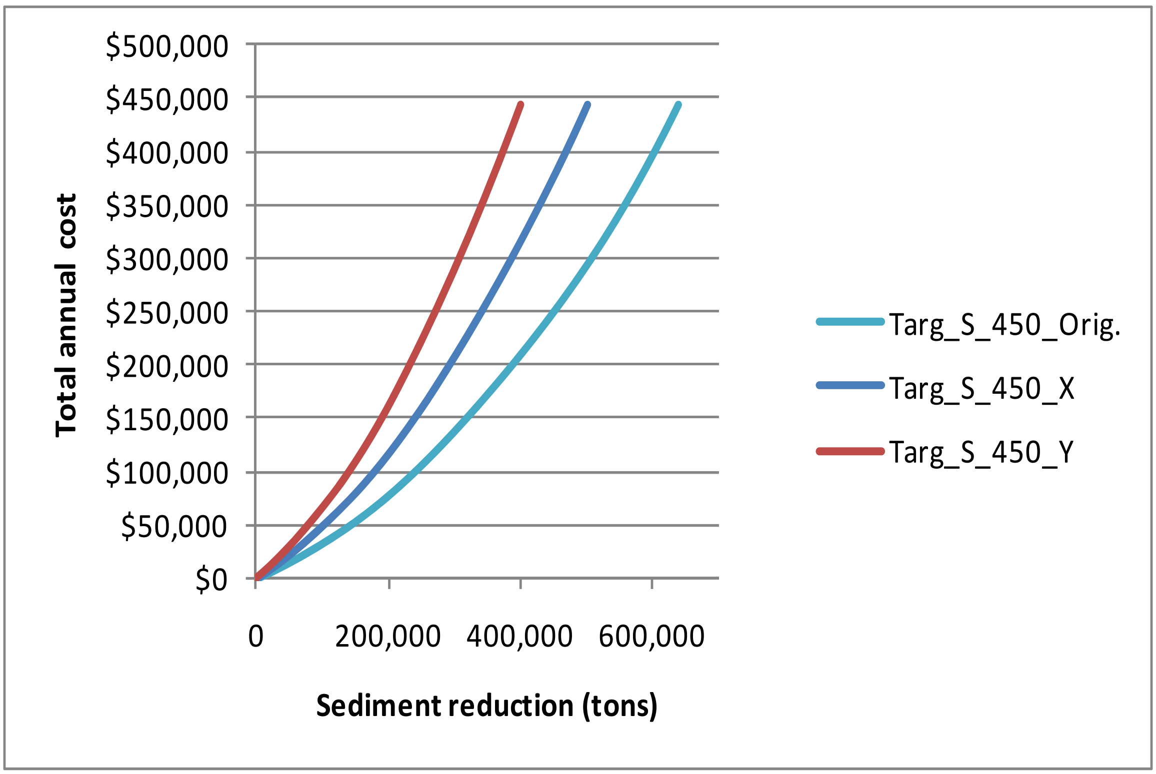

Figure 13 Sediment total cost curves for different BMP cost levels

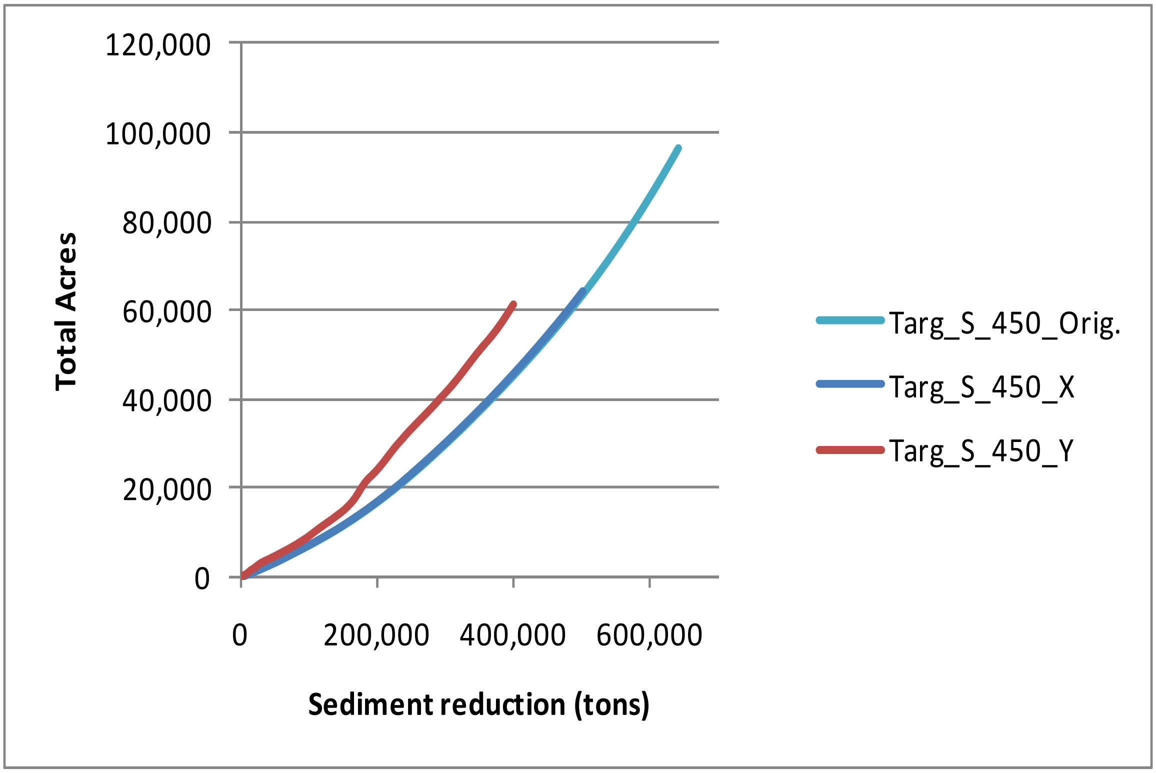

Figure 14 Total acres treated by BMPs for different BMP cost levels (Sediment)

Cost-effective spatial targeting for conservation

In principle, spatial conservation targeting is no different. It is the deliberate focus of BMP implementation on a particular geographical area. Implementing BMPs in areas that exhibit the most potential for erosion is a good first step in efficient targeting. This approach to targeting could simply rely on a baseline sediment loading map displayed in Figure 15.

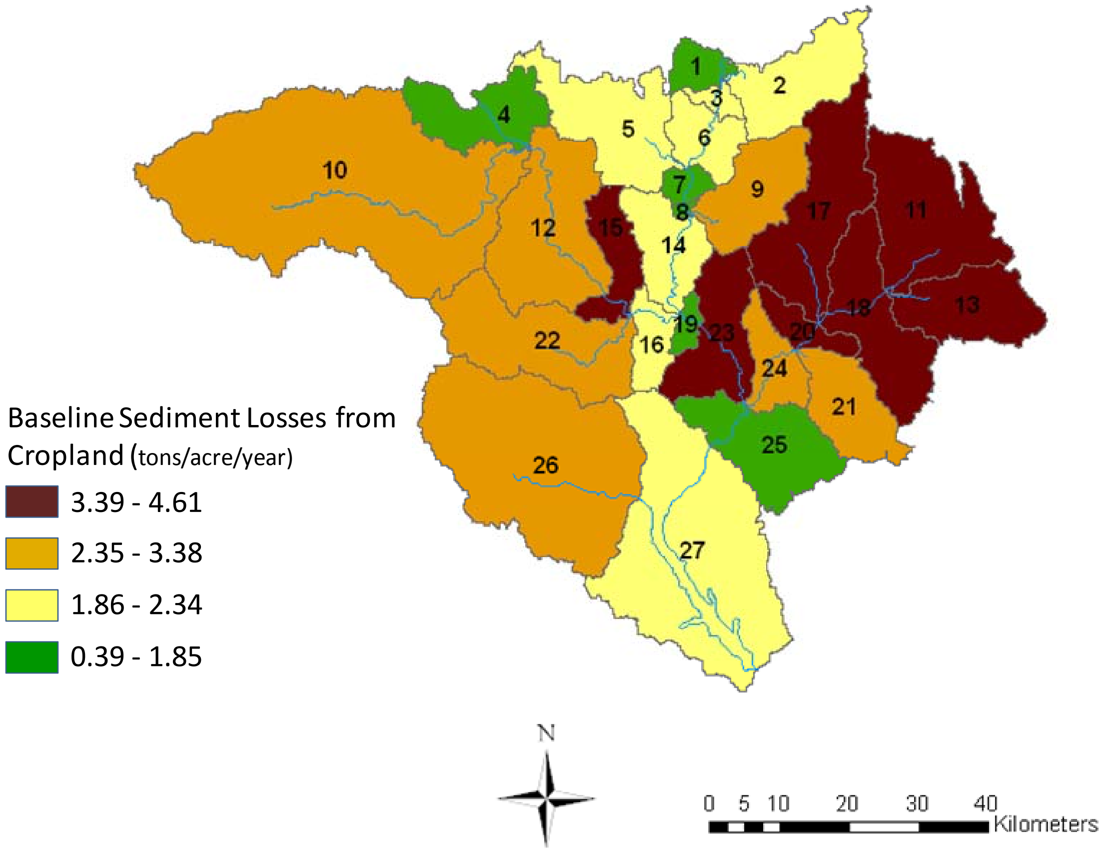

Figure 15 Baseline sediment losses from cropland by subwatershed

However, this may not be the most cost-effective technique because costs are not being considered. Cost-effective conservation spatial targeting includes the economics of pollutant reduction and focuses BMPs in areas of the watershed, which deliver the greatest benefits (pollutant reduction) for the cost.

Using the targeted approach discussed in previous sections, prescriptions for cost-effective spatial targeting can be derived. The process for determining target areas is described next.

The spatial targeting approach described here answers the question: Where in the watershed will a given BMP (i.e., filter strips, no-till, or permanent vegetation) provide the most cost-effective sediment reduction? This targeting approach is performed with the original BMP costs as well as for the adjusted BMP costs used in the "Y" scenarios described previously. For obvious reasons, only the targeted scenarios (not the random) are used. No farms are deleted or eliminated from the choice set. The budget constraint and pollutant reduction goals are both set infinitely high, so that all possible BMPs are implemented. Only one iteration is run to produce the results necessary to determine the cost-effective spatial targeting prescriptions.

The results from one iteration provide information on the costs and pollution reduction achieved by implementing a given BMP on a farm. Each farm is located in one of the 27 subwatersheds. Using the cost, pollution reduction, and the acreage being treated by the BMP, acre-weighted averages are calculated for each subwatershed. A $6.69/ton sediment acre-weighted average reduction costs for subwatershed 1 reported in the first cell of Table 13 indicates that for an average acre in this subwatershed, sediment can be reduced for $6.69/ton.

This is more cost-effective than implementing BMPs in subwatershed 8, which exhibits $16.69/ton sediment reduction costs, but not near as cost-effective as investing in filter strips in subwatershed 17.

The targeting calculations also are performed for the “Y” scenarios. The “Y” scenarios represent the case where the total annualized costs for filter strips and permanent vegetation are increased by 200 percent to capture a more drastic increase in land opportunity costs and fuel prices. For no-till, the annualized costs were decreased by 75 percent to account for the even higher fuel prices, and thus, a greater relative cost advantage of no-till (all else equal). The results for the “Y” scenarios are displayed in Table 14.

Table 13 Acre-weighted average sediment reduction costs for Targ_S_$$$_Orig. scenarios for each BMP

	Filter Strips	No-till	Permanent vegetation
Subwatershed	Sediment ($/ton)	Sediment ($/ton)	Sediment ($/ton)
1	$6.69	$78.82	$98.00
2	$3.24	$32.84	$47.63
3	$3.43	$31.99	$50.48
4	$3.63	$35.45	$50.30
5	$3.45	$33.07	$49.93
6	$3.39	$30.77	$49.73
7	$3.90	$35.82	$56.96
8	$16.69	$158.06	$238.95
9	$2.53	$23.49	$37.41
10	$2.20	$21.16	$31.12
11	$1.43	$12.42	$21.16
12	$2.07	$18.72	$29.00
13	$1.81	$14.49	$26.34
14	$2.81	$25.75	$41.13
15	$1.83	$17.06	$26.53
16	$2.95	$27.17	$43.05
17	$1.36	$11.15	$19.86
18	$1.48	$13.55	$21.50
19	$4.47	$41.41	$65.19
20	$1.65	$14.28	$23.81
21	$1.61	$15.20	$23.80
22	$2.52	$23.02	$35.31
23	$1.56	$14.39	$23.04
24	$2.38	$20.52	$34.31
25	$2.62	$22.81	$39.05
26	$2.36	$21.86	$33.58
27	$2.29	$17.55	$32.85

Table 14 Acre-weighted average sediment reduction costs for Targ_S_$$$_Y scenarios for each BMP

	Filter Strips	No-till	Permanent vegetation
Subwatershed	Sediment ($/ton)	Sediment ($/ton)	Sediment ($/ton)
1	$13.37	$19.70	$196.00
2	$6.47	$8.21	$95.26
3	$6.86	$8.00	$100.95
4	$7.25	$8.86	$100.61
5	$6.89	$8.27	$99.86
6	$6.78	$7.69	$99.46
7	$7.80	$8.96	$113.91
8	$33.37	$39.52	$477.90
9	$5.06	$5.87	$74.81
10	$4.40	$5.29	$62.25
11	$2.86	$3.10	$42.32
12	$4.15	$4.68	$58.01
13	$3.62	$3.62	$52.68
14	$5.63	$6.44	$82.26
15	$3.67	$4.26	$53.06
16	$5.91	$6.79	$86.10
17	$2.72	$2.79	$39.73
18	$2.96	$3.39	$43.00
19	$8.95	$10.35	$130.38
20	$3.31	$3.57	$47.62
21	$3.22	$3.80	$47.61
22	$5.04	$5.75	$70.61
23	$3.13	$3.60	$46.09
24	$4.77	$5.13	$68.63
25	$5.24	$5.70	$78.11
26	$4.71	$5.47	$67.15
27	$4.59	$4.39	$65.71

The data in Table 13 and Table 14 may be better represented in map form. Dividing each of the scenario's results into "quartiles," cost-effective conservation spatial targeting maps are created. [12] In other words, sorting the average costs for a given scenario in ascending order and then dividing the data into four groups of seven subwatersheds each is a useful way of presenting the results cartographically. Individual maps are created for each of the 6 scenarios covered in Table 13 and Table 14. Upon closer inspection, the spatial priority ranking of the subwatersheds is identical across the original cost scenarios and the adjusted "Y" cost scenarios. For this reason, only the maps for the "Y" scenarios (which correspond with Table 14) will be analyzed here. The remaining maps for the original cost scenarios can be found in Smith (2011).

[12] The word "quartiles" is in quotes because the number 27 is not perfectly divisible by 4. So, the quartiles used here contain 7, 7, 7, and 6 subwatersheds in the high, medium-high, medium-low, and low categories.

Figure 16 has been included to give the reader an indication of which watercourses are located in the economically derived priority areas. It displays the locations of the major rivers and creeks in the Kansas portion of the TCL watershed. Figure 17 shows the priority areas in the TCL watershed for reducing sediment via filter strips. According to this figure, the most cost-effective sediment reducing locations for placing filter strips is in the east-northeast portion of the watershed. Particularly, subwatersheds 11, 13, 17, 18, 20, 21, and 23. Sediment can be reduced for $2.72 to $3.62/ton annually. The poorest places (from a cost-effectiveness standpoint) for sediment reducing filter strips are subwatersheds 1, 4, 5, 7, 8, and 19. Here, sediment reduction costs are much higher ranging from $6.87/ton up to $33.37/ton annually. In general, the north-central portion of the TCL watershed is the least cost-effective region to place filter strips for sediment reduction.

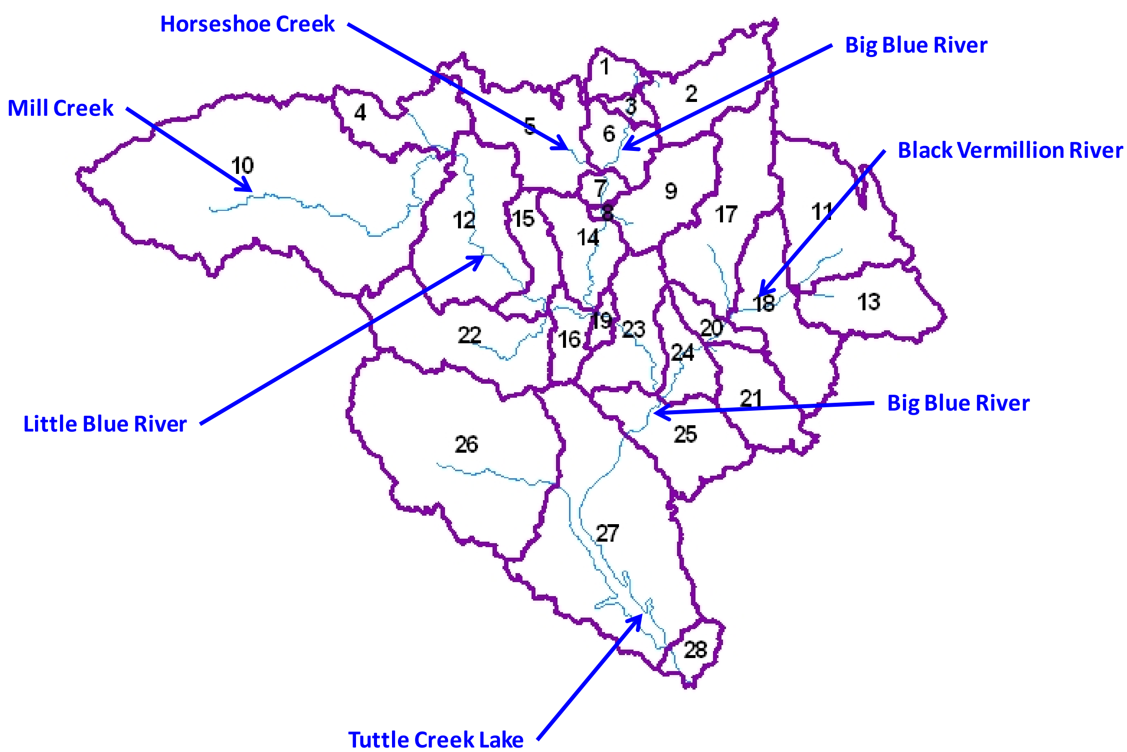

Figure 16 Major watercourses and subwatershed delineation for the TCL watershed

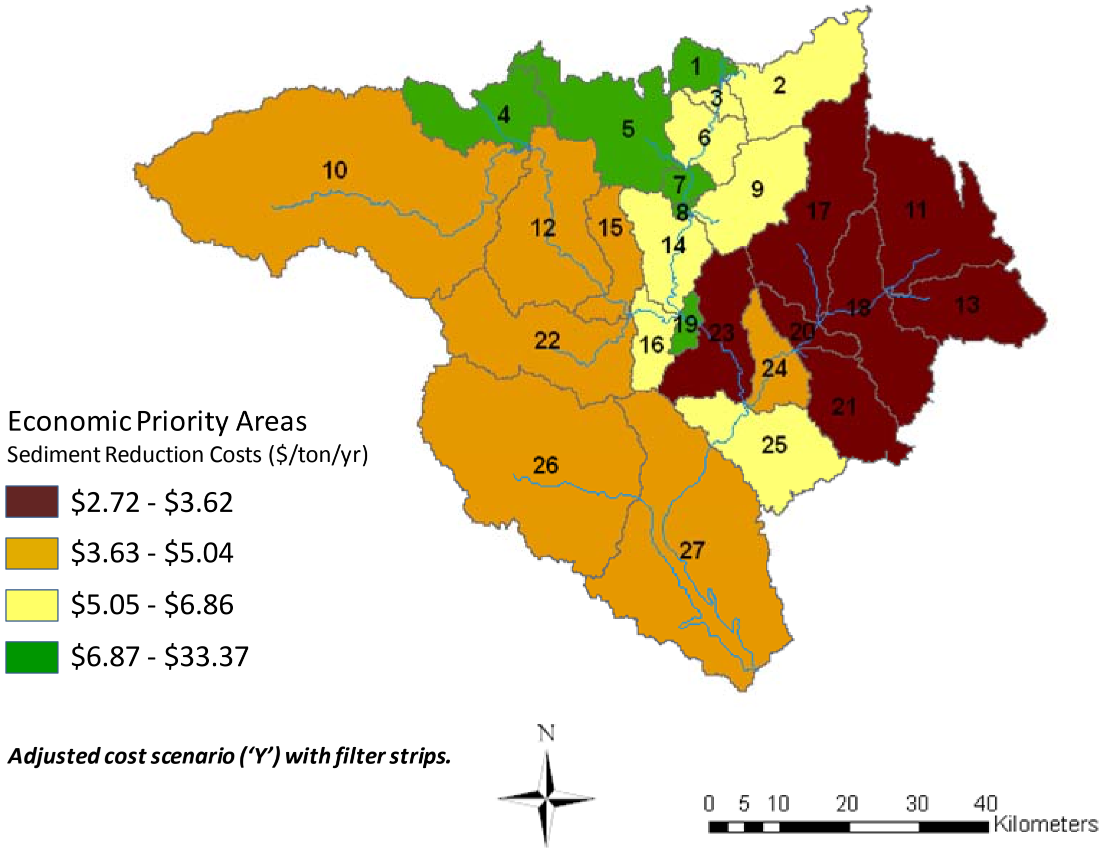

Figure 17 Spatial average sediment reduction costs under adjusted ("Y") costs with filter strips

Figure 18 displays the average annual sediment reduction costs when no-till is applied in each of the subwatersheds. The most cost-effective sediment reducing locations for placing no-till is again in the east-northeast portion of the watershed. Particularly, subwatersheds 11, 13, 17, 18, 20, 21, and 23. Here, sediment can be reduced for $2.79 to $3.80/ton annually. The poorest places (from a cost-effectiveness standpoint) for sediment reducing no-till are subwatersheds 1, 4, 5, 7, 8, and 19. Here, sediment reduction costs are much higher ranging from $8.22/ton up to $39.52/ton annually. In general, the north-central portion of the TCL watershed is not the most cost-effective region to place no-till for sediment reduction.

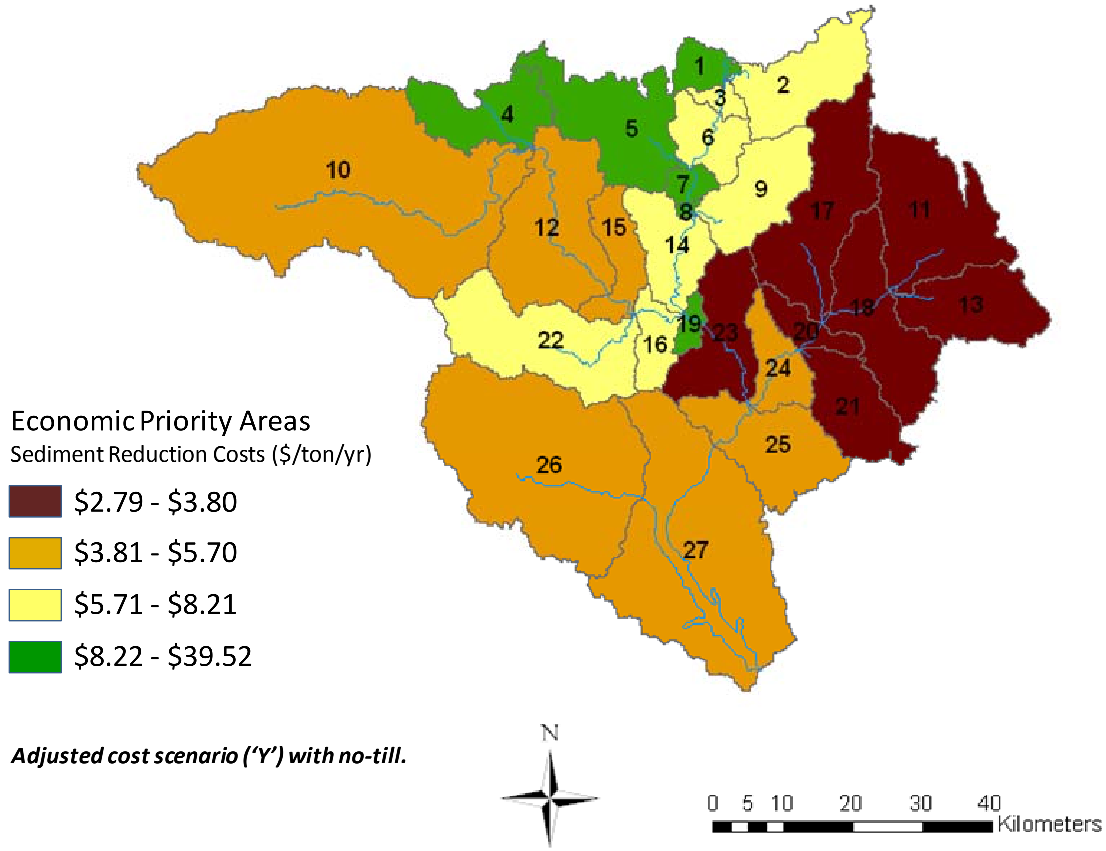

Figure 18 Spatial average sediment reduction costs under adjusted ("Y") costs with no-till

Figure 19 displays the annual average sediment reduction costs with permanent vegetation. In general, sediment reduction is over 10 times higher in cost-effectiveness terms for permanent vegetation compared to no-till. The high priority areas identified here are the same as in the cases of filter strips and no-till. The low priority subwatersheds, however, deviate slightly. Subwatershed 5 is low priority in the cases of filter strips and no-till, but is medium-low priority in the case of permanent vegetation. Subwatershed 3 is instead identified as low priority with permanent vegetation.

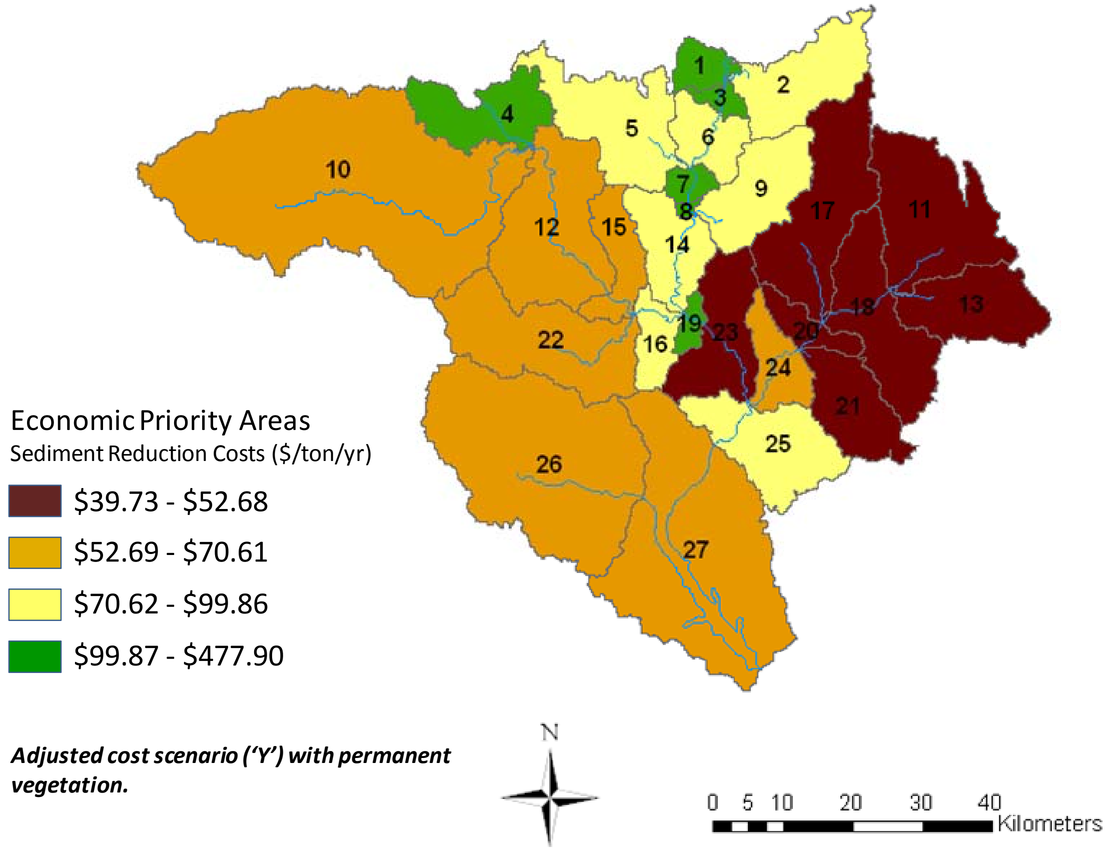

Figure 19 Spatial average sediment reduction costs under adjusted ("Y") costs with permanent vegetation

Characteristics of economically targeted areas

As described previously, the economically targeted areas take into account both the physiographical and the economic characteristics of the farm (or HRU) and the BMP. In general, the three primary physiographical factors affecting sediment runoff and contribution to TCL for a given farm and BMP are land slope, hydrologic soil group, and delivery ratio. Thus, it would be expected that subwatersheds 11 and 13 (the most cost-effective subwatersheds for BMP implementation) would exhibit different physiographical characteristics than subwatersheds 1, 8, and 19 (three of the least cost-effective subwatersheds for BMP implementation).

Based on information in Table 2, subwatershed 19 actually has a much greater percentage of land with slopes greater than 6 percent than either subwatershed 11 or 13. However, only 49.6 percent of the land in subwatershed 19 is classified as being in hydrologic soil group D. This compares to 96.7 and 93.5 percent of the land in subwatersheds 11 and 13. Subwatersheds 1 and 8 have 0.0 and 50.3 percent of land with "D" soils, respectively. In terms of delivery ratios for sediment (Table 7), subwatershed 19 has the highest at 1.00 while subwatersheds 1, 8, 11, and 13 have sediment delivery ratios of 0.56, 0.69, 0.69, and 0.66, respectively. From this, it appears that soil type is driving much of the differences in sediment contribution to TCL. However, the physiographical characteristics that make up each subwatershed only put into picture part of the story. The economic characteristics help to explain the other part.

Each of the 5 subwatersheds described previously are contained completely or partially in Marshall County, Kansas. Subwatersheds 8 and 19 lay completely in Marshall County. Over 90 percent of subwatershed 1 is contained in Gage County, Nebraska with the remaining 10 percent in Marshall County. Subwatershed 11 is 64 and 36 percent in Marshall and Nemaha counties, respectively. Subwatershed 13 is 27 and 73 percent in Marshall and Nemaha Counties, respectively. Of the counties in Kansas, Nemaha county exhibits the highest annualized costs for filter strips and land retirement with permanent vegetation. Gage County, Nebraska exhibits the highest annualized costs across all of the counties considered here. Thus, it appears that while high land opportunity costs make subwatersheds 11 and 13 less attractive, the relatively large pollutant loading and levels of BMP effectiveness make these subwatersheds prime spots for cost-effective BMP investments.

What does all of this mean for cost-effective targeting? Cost-effective targeting is not as simple as looking at just one factor such as land slope or land opportunity costs. While soil type appears to be a good indicator of targeting, relying heavily on it can even be misleading. For example, 99 percent of the soils in subwatershed 9 are hydrologic group D. This subwatershed ranks number one in this respect. However, this subwatershed should be medium-low priority for sediment reduction with filter strips. At least in the case of TCL watershed, cost-effective targeting can only occur when all relevant physiographical and economic factors are considered.

DREDGING VERSUS BMPS

TCL and its watershed are used as a case-study to examine the economics of watershed protection and reservoir rehabilitation including dredging. TCL exhibits, perhaps, one of the most critical cases of reservoir sedimentation in Kansas and throughout the Midwest. As of 2009, which was 47 years since the reservoir was completed, TCL contained 180,378 acre-feet of sediment. With over 42 percent (Table 15) of its total original storage capacity (425,312 acre-feet) lost to sediment accumulation, TCL provides a unique and fitting case-study example for this analysis.

Table 15 Tuttle Creek Lake and watershed characteristics and dredging costs

Characteristics	
Original conservation storage pool (acre-feet)	425,312
Sediment deposited as of 2009 (acre-feet)	180,378
Sediment deposited as of 2009 (cubic yards)	291,009,849
Sediment deposited as of 2009 (tons)	291,009,849
Total drainage area (square miles)	9,628
Total drainage area (acres)	6,161,920
Kansas portion of Tuttle Creek watershed	
Portion of drainage area - KS portion (%)	25%
Drainage area - KS portion (square miles)	2,377
Drainage area - KS portion (acres)	1,521,554
Pastureland/Rangeland - KS portion (%)	42%
Pastureland/Rangeland - KS portion (acres)	646,639
Cropland - KS portion (%)	43%
Cropland - KS portion (acres)	649,548
Other - KS portion (%)	15%
Other - KS portion (acres)	225,367
Dredging costs in 2009	
Cost per cubic yard or ton	$4.11
Dredging and disposal cost per acre foot	$6,631
Sediment deposited as of 2009 (acre-feet)	180,378
Cost to remove sediment deposited until 2009	$1,196,050,480
Onetime equivalent costs	
Cost per total watershed-acre	$194.10
Cost per cropland acre (total watershed)	$269.59

Dredging

Dredging is the removal of accumulated lake bottom sediments. This removal process can take place through mechanical, hydraulic, or pneumatic means (Hudson 1998). Sediments are frequently removed from our nation's rivers and ports for navigation and boating purposes. Although less common, dredging can also take place in lakes and reservoirs as a way of reclaiming water storage capacities. While there are many aspects to consider with dredging projects, one important consideration is cost.

As Williams and Smith (2008) point out, the decision on whether or not to dredge will depend on sediment source, sedimentation rate with and without management practices, effectiveness and cost of management practices, dredging cost inflation, the planning horizon, and the discount rate used to calculate present values. If accumulated sediment has not negatively impacted current reservoir services (e.g., recreation, flood control), then it might be reasonable to forego dredging in favor of investing in additional in-field and in-stream conservation practices to reduce the need for future dredging.

As part of this process, dredging cost data were collected from the U.S. Army Corps of Engineers historical dredging database (USACE 2011). These costs include the cost of maintenance dredging, as well as mobilization of equipment and costs of disposal. The smaller the project the larger the mobilization cost is as a percent of overall costs. Both Corps and industry managed projects are included in the calculations. Figure 20 displays the historical trend in dredging costs in nominal dollars. From a low of $0.30 per cubic yard in 1970 to a high of $4.11 per cubic yard in 2009, dredging costs have exhibited an average inflation rate of 6.94 percent over this 39 year period.

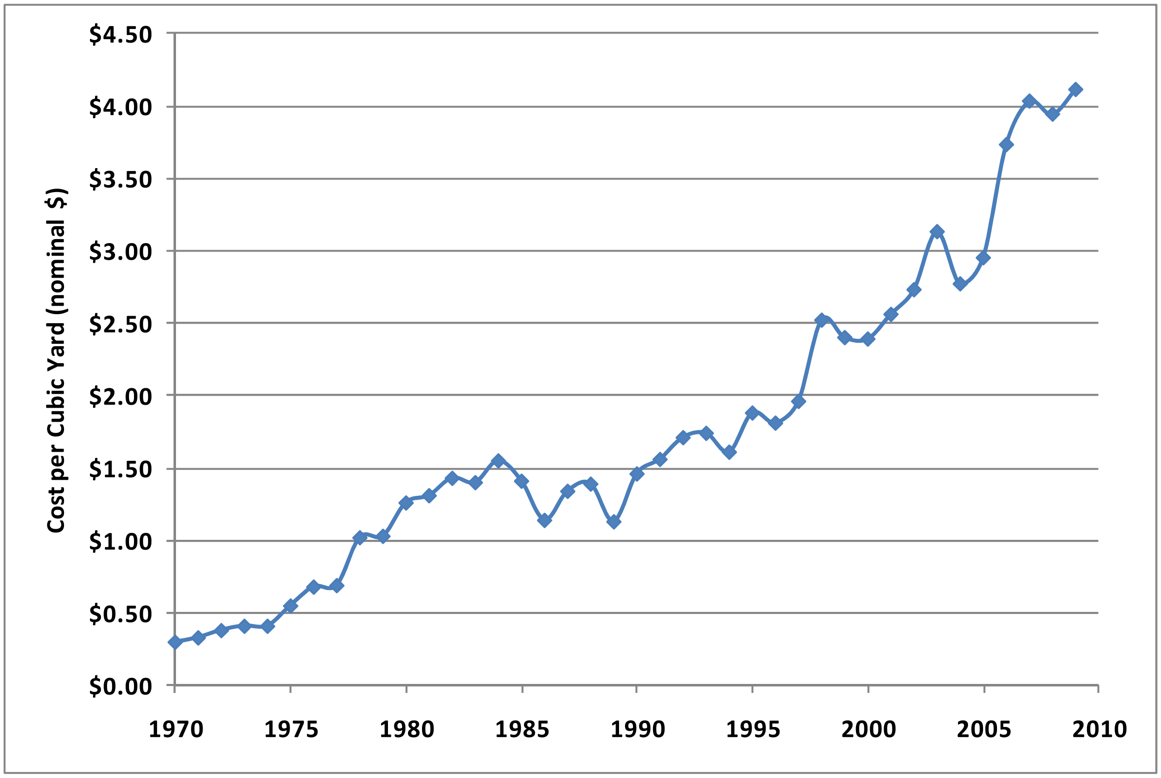

Figure 20 Historical dredging costs in nominal dollars

The cost of constructing TCL in 1962 dollars was $80,051,031. Given an annual inflation rate of 6.94 percent (consistent with the average inflation of dredging costs) in construction costs, the cost in 2009 dollars is $1,096,699,225. If $6.45 per cubic yard were spent to dredge 291,009,874 cubic yards from the lake, it would approximately equal the construction cost in 2009 dollars. At a dredging cost of $4.11 per cubic yard, it would cost $1,196,050,480 (or $194 per total watershed-acre) to restore TCL to its original storage capacity (Table 15). Clearly, dredging is an expensive option.

While reservoir sedimentation and dredging data are typically in acre-feet or cubic yards units, soil erosion figures are typically reported in tonnage. Since each of these processes will be compared in this analysis, a common unit of measurement is needed. According to Holland (1971), past sediment samples from Kansas reservoirs exhibited (dry) soil bulk densities of approximately 0.82 tons/yd^3. Other studies have specified cropland soil bulk densities in the ranges of 0.94 to 1.43 tons/yd^3 (NYSSESC 2005) and 1.01 to 1.35 tons/yd^3 (Hillel 1998) depending on the soil characteristics (i.e., more clay content yields lower soil bulk density values). For simplicity, we will assume a ratio of 1 ton per 1 cubic yard. Thus, a 2009 dredging cost of $4.11 per cubic yard is equal to $4.11 per ton. This will be used as a starting point for the following analysis.

Under the adjusted BMP cost assumptions, Table 12 shows that all of the targeted "Y" scenarios up to a $450,000 annual budget result in average sediment reduction costs of much less than $4.11 per ton. But, the marginal cost curves were increasing at an increasing rate. While dredging is expensive, there may be some point at which it becomes more feasible than spending additional money on BMP implementation. What is the transition point at which it becomes more cost-effective to dredge (either now or in the future) rather than spend more money on BMP implementation?

Case 1: Implement BMPs and/or dredge beginning in year 1 (i.e., year 2009)

Several simplifying assumptions are made in the following case study. This case assumes perfect substitutability and equality between preventing a ton of soil from reaching TCL via BMP implementation and dredging a ton of sediment from TCL. Each results in one less ton of sediment in TCL at the end of each year. While there are other non-monetary benefits and costs associated with each of the BMP methods, these are not directly accounted for in this analysis.

The cost of dredging in year 1 is equal to $4.11 per ton. The average annual cost preventing sediment from reaching TCL via the three BMPs analyzed previously is $1.11 per ton for a $450,000 budget. Graphing the marginal and total cost curves for sediment reduction according to the assumptions of Targ_S_$$$_Y (i.e., targeted sediment reduction scenario with adjusted BMP costs and unlimited budget) shows that BMP implementation is economically preferred to dredging for the first 603,414 tons of sediment per year or $915,274 annual budget. In other words, all funds should be directed towards BMP implementation if operating under an annual budget of less than $915,274 per year. Or, if there are more than $915,274 in funding available for the restoration and/or protection of TCL, then the first $915,274 should be spent on BMPs and any remaining funds should be directed towards dredging (note, this is ignoring any other possible benefits provided by watershed BMPs). Figure 21 graphically shows the points of transition.

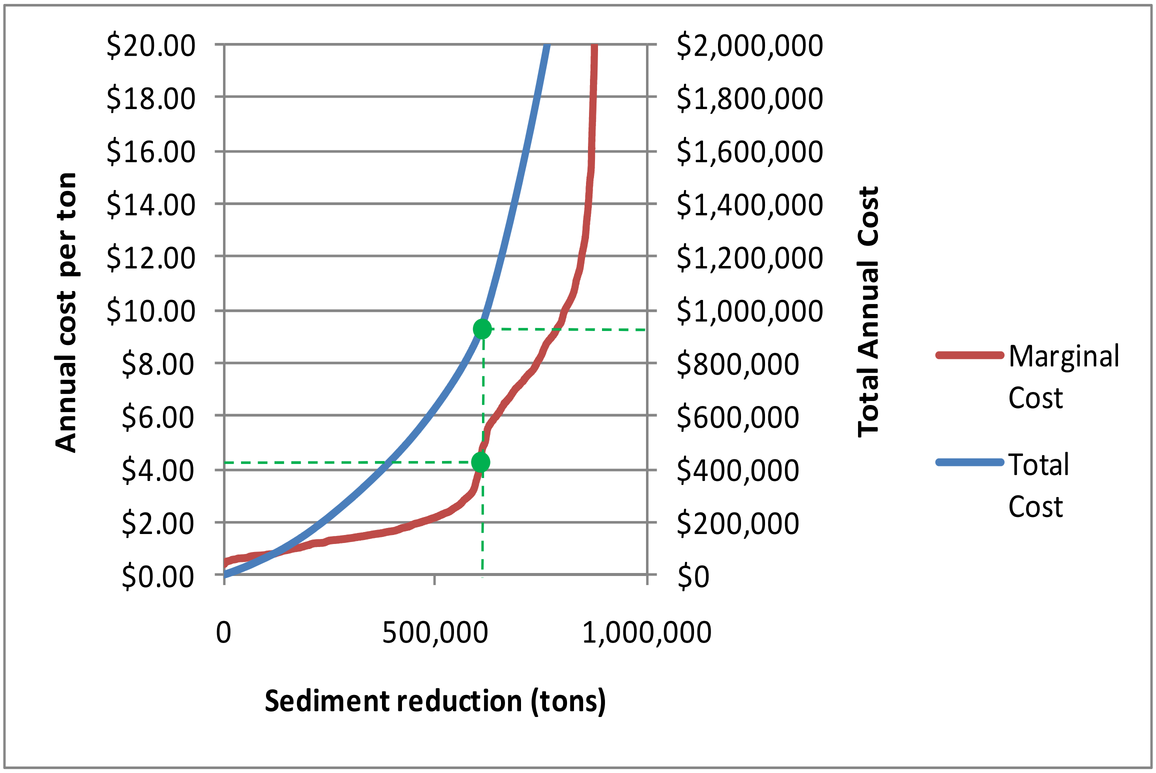

Figure 21 Marginal and total cost curves for sediment reduction for Targ_S_$$$_Y (Case 1)

The above prescription assumes that BMPs are implemented in a highly targeted or "optimal" approach. If targeting of BMPs is not an option, then the prescription here would be to immediately spend the funds dredging. This is based on Figure 22 which shows the Rand_S_$$$_Y scenario along with a line equal to the constant marginal cost curve of dredging at $4.11 per ton. The average cost of reducing sediment via BMPs without any targeting is $32.49 per ton which is nearly 8 times higher than the cost of dredging.

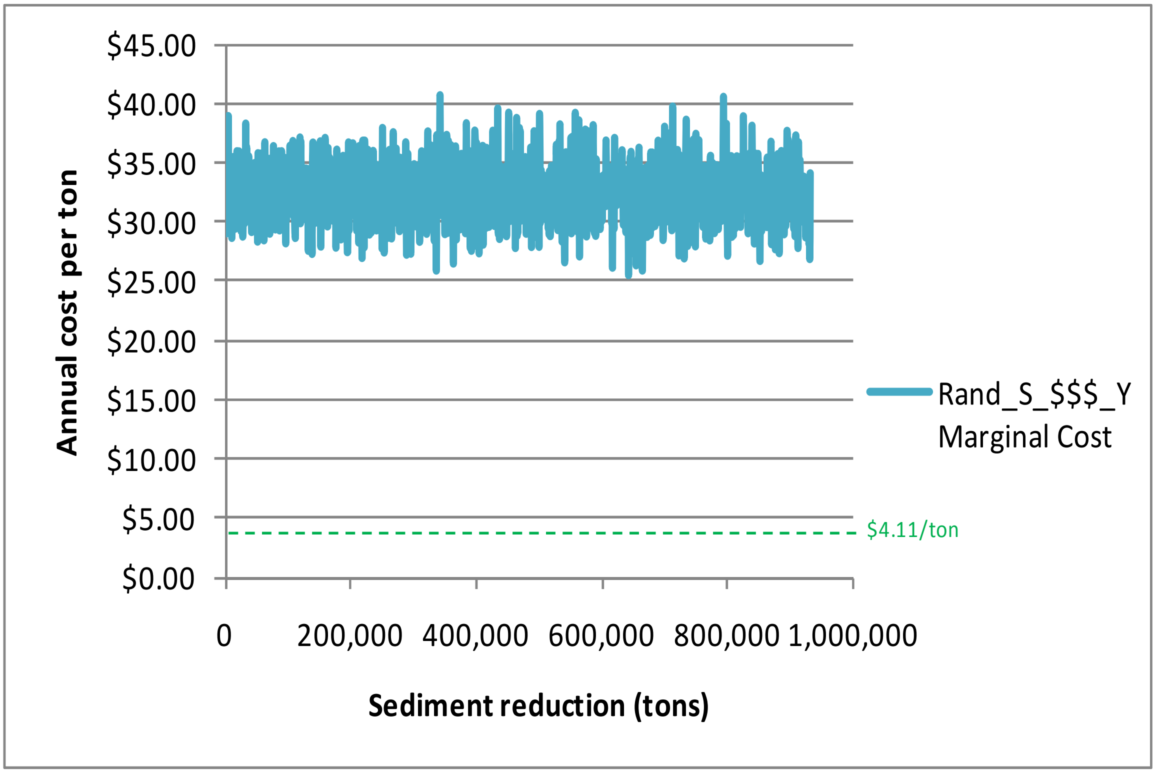

Figure 22 Marginal cost curve for sediment reduction for Rand_S_$$$_Y (Case 1)

Case 2: Implement BMPs in year 1and dredge beginning in year 16

The second case describes a situation in which BMPs are implemented in years 1 through 15. Then, beginning in year 16, dredging will occur. The question is: What are the savings in dredging costs realized in year 16 due to the implementation of BMPs in years 1 through 15?

This calculation is essentially calculating the present value of the cost of dredging in 15 years. Beginning with a current cost of dredging of $4.11 per ton, a 6.94 percent inflation rate, and a 15 year analysis period, the future value of dredging (at the beginning of year 16) is calculated to be $11.25 per ton. Converting this to present value terms using a discount rate of 4.625 percent (NRCS 2009) yields a present value of $5.71 per ton. The higher inflation rate relative to a lower discount rate results in a present value of dredging in 15 years value that is higher than current dredging costs. From an economic perspective, if dredging is to be delayed 15 years or more, more money can be justifiably spent on BMP implementation.

As Figure 23 depicts, up to $1,047,959 should now be spent on targeted BMP implementation. This is an increase of $132,685 per year due to the decision to delay dredging until year 16. This amounts to 629,488 tons of annual sediment reduction. Coincidentally, this also happens to approximately be the point at which the marginal cost curve becomes effectively vertical.

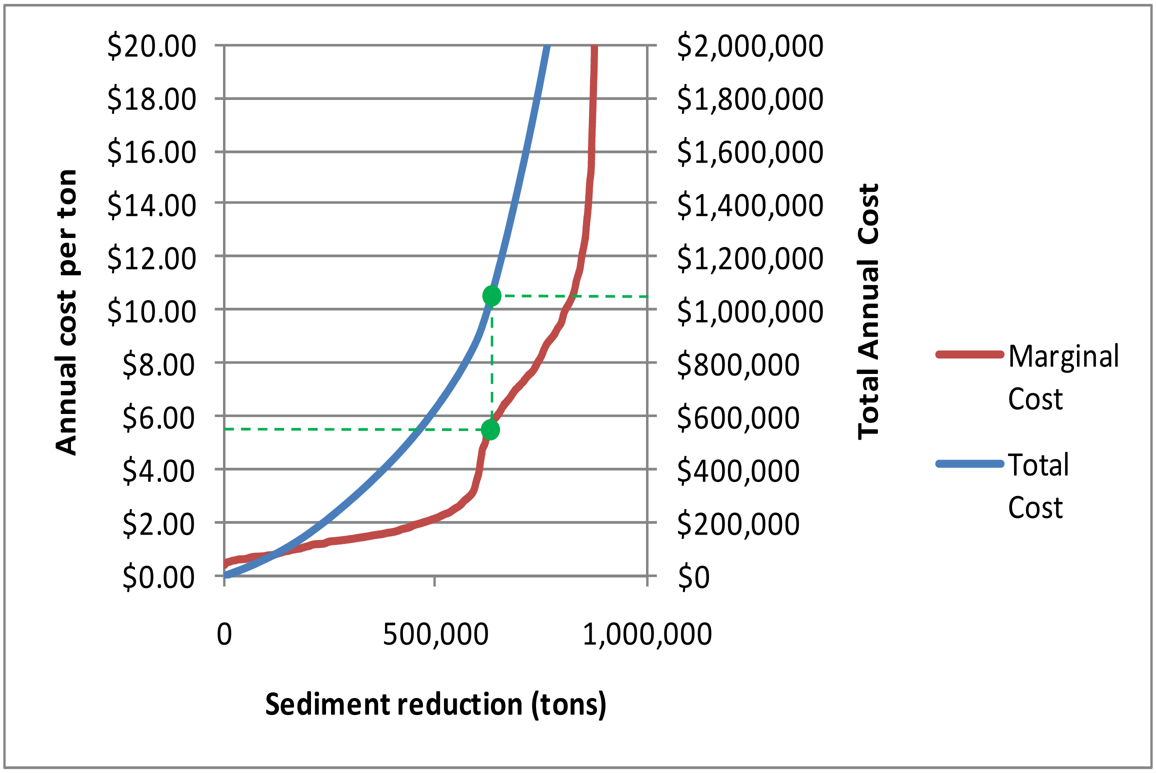

Figure 23 Marginal and total cost curves for sediment reduction for Targ_S_$$$_Y (Case 2)

As stated earlier, this finding is simply a function of the inflation to discount rate difference. If the two rates were set equal, then the prescription from Case 2 would essentially be no different from the prescription from Case 1. In other words, the point at which funding should be taken away from BMP implementation is the same. Conversely, if the discount rate was higher than the rate of inflation, less money should be directed towards BMP implementation because dredging is going to relatively cheaper in the future.

In all cases and scenarios, if BMPs can only be implemented in a random fashion, the prescription would be to forego all BMP implementation in favor of dredging now or in the future. This is because random BMP implementation is between 5 to 8 times more costly than current or delayed dredging costs.

CONCLUSION

This paper answered the question: How can physiographical and economic relationships within the watershed be quantified to provide insights into the selection of cost-effective alternative management strategies? This question was addressed by integrating a geographic information system (GIS) based watershed model, reservoir rehabilitation management strategies, statistical analyses of historic watershed and water quality data, with an economic analysis of alternative sedimentation reduction strategies. The following are some of the key findings, which can offer decision-makers better insight into the benefits and cost implications associated with achieving various water quality levels and sedimentation reduction goals within a large watershed.

Both physiographical and economic factors must be considered for cost-effective conservation to occur.

Consideration of only one side (i.e., either physiographic or economic) of a soil and water resource issue will not result in an optimal strategy from a cost-effectiveness standpoint. Targeting areas that produce the most pollution per acre is more cost-effective than a random approach, but may miss the mark if those areas also exhibit high BMP costs (e.g., due to high opportunity costs). Likewise, focusing only on areas where BMP costs are low may produce "better than random" results, but may not achieve cost-effective pollution reduction if the areas do not exhibit high levels of pollutant reduction.

Optimal BMP targeting is up to 23 times more cost-effective than random implementation, but also is likely to be more costly to administer.

Random BMP implementation is not an effective method for funding and placing BMPs. This is somewhat representative of a policy where conservation funds are issued to any interested and willing landowner in a county or watershed. While this approach achieves equity, conservation dollars are being spent in areas that do not deliver a good "bang for the buck" relative to other areas. Specifically, a targeted approach can reduce 23 times more sediment for a given budget than a random approach. It should be noted, however, that a highly targeted approach can be costly from an administration standpoint.

BMP implementation is more cost-effective than dredging if done in a targeted manner, but not if randomly implemented.

In the case of TCL watershed, if conservation funds cannot be implemented in a highly targeted manner, then it may, in fact, be more cost-effective to allocate funds for dredging. Annualized dredging costs are around \$5.00 per ton whereas annualized "random" BMP implementation costs average approximately \$30.00 per ton. Under a targeted approach, approximately 1 million dollars per year could be spent on BMP implementation before any funds are spent on dredging. In other words, the marginal costs of BMP implementation are less than \$5.00 per ton up to approximately 1 million dollars in annual total cost.

Up to approximately 1 million dollars per year, not considering "intangible" costs of BMP implementation, could be spent on targeted BMP implementation before some selected dredging may be needed.

"Intangible" costs represent all those costs other than pure accounting costs, which a farmer may take into consideration when deciding whether to implement a given BMP. Examples may include: various hassle factors, need for additional training/education, and/or concern of more future government regulation if participating in a conservation program. This report only included the accounting costs of adopting BMPs, and thus, may have underestimated the total costs of BMP implementation.

However, the original BMP costs were adjusted to reflect more current-day economic values. These adjusted "Y" cost scenarios were used in the dredging cost analysis. Based on this, approximately 1 million dollars could be spent on targeted BMP implementation before any funds are spent on dredging.

If "intangible" costs of BMP implementation costs are significant and/or BMPs cannot be targeted effectively, dredging is likely more cost-effective.

In general, reservoir dredging has been looked upon as a very expensive approach to reducing reservoir sedimentation. However, it may not be entirely cost-prohibitive on an annualized per unit basis. Relatively low "intangible" costs and/or effective targeting are necessary conditions that must exist for BMP implementation to be more cost-effective than dredging. If either one of these conditions does not hold, dredging may in fact be a more cost-effective approach to addressing sedimentation in TCL. Again, random BMP implementation results in average costs of sedimentation reduction of nearly $30 per ton whereas dredging costs average $5 per ton.

Limitations and future research needs

While this research analyzes and compares the cost-effectiveness of various BMP implementation approaches in the TCL watershed with dredging, the benefits associated with each of these strategies have not been addressed. Other limitations of this study are that only three in-field cropland BMPs are included in the analysis, and streambank stabilization strategies were not considered. In addition, only the Kansas portion (~25 percent) of the entire TCL watershed was considered for BMP application. In other words, "business as usual" is assumed to be the case for the Nebraska portion. There may, in fact, be value related to an interstate cooperative approach to address these issues. To be clear, a comprehensive benefit-cost analysis is not performed in this study. The following discussion highlights some of the limitations of this study and makes recommendations for future areas of research related to BMP implementation, dredging, and reservoir sedimentation in general.

While this analysis compares BMP implementation to dredging from a cost standpoint, this is only half of the story. The benefits created or preserved by each activity must be considered to adequately analyze these management alternatives. Consider the following as a foreword to some of the relevant benefits.

The application of BMPs to reduce soil erosion and nutrient (not considered here) runoff can result in benefits to a watershed region that may not be directly linked to the downstream reservoir (i.e., TCL). BMPs can improve soil productivity over time, which is a benefit to landowners. Improved wildlife habitat for hunting and other related recreation benefits in the watershed above the reservoir also may be created or preserved through BMP implementation. Further, benefits related to improved water quality in streams and rivers may be non-additive. That is, a reduction in nitrogen runoff close to a stream located far away from the reservoir may actually be more valuable to society than a reduction of soil erosion in a field bordering the reservoir. Our analysis only considers the costs and pollutant reductions achieved by BMP implementation and does not attempt to quantify any of the other benefits.

To the extent that society values carbon sequestration in the future, BMP implementation could result in benefits that accrue to society at large and not just those in the watershed or reservoir users. It also may be likely that users of water downstream of TCL would benefit from improved water quality attributable to BMPs.

The possibility of changes in climatic conditions and the impacts of those changes are other wild cards in this discussion. Climatic changes may significantly affect water use, water quality, and TCL watershed ecosystem services. Less frequent but more intense rainfall events or even more droughty conditions may increase the use and benefits of BMPs. The possibilities of these additional benefits and the growth of them would need to be considered in a more comprehensive benefit-cost analysis.

There does not exist a current, comprehensive analysis of the benefits generated by all of the resources in and around TCL or any of the conservation practices implemented throughout the watershed. A 2001 Army Corps of Engineers study estimated benefits generated by TCL, but this study focuses solely on the reservoir (USACE 2001). Without much provided detail, it is likely that this study did not include many of the non-market benefits of TCL. A more comprehensive, watershed-wide analysis of costs and benefits (including non-market values) would be necessary to more adequately compare the various alternatives for protecting and/or restoring TCL: BMP implementation to dredging to BMP implementation with dredging to "do-nothing".

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APPENDIX A: SWAT MODEL DESCRIPTION AND DETAILS

The goal of this stage of the study is to calibrate the Soil and Water Assessment Tool (SWAT) for the Tuttle Creek Lake (TCL) watershed (HUC-10270207 and HUC-10270205). Two major rivers (Big Blue River and Little Blue River) discharge water and sediment to TCL. Therefore, there is a need to estimate and incorporate flow and sediment inputs from these rivers (inlets). The locations of the inlets are identified in Figure 24.

In order to estimate sediment input to the TCL watershed, we set up and calibrated two watersheds for flow and sediment. We called the first watershed Upper Left (HUC 10270207), which contains the Little Blue River. The second watershed was named the Upper Right (HUC-10270201, HUC-10270202, HUC-10270203, and HUC-10270204), which contains the Big Blue River. The two watersheds are identified in Figure 25. The results from the calibrated models above were used as inputs to the TCL watershed. The final stage involved calibration of the TCL watershed for flow and sediment.

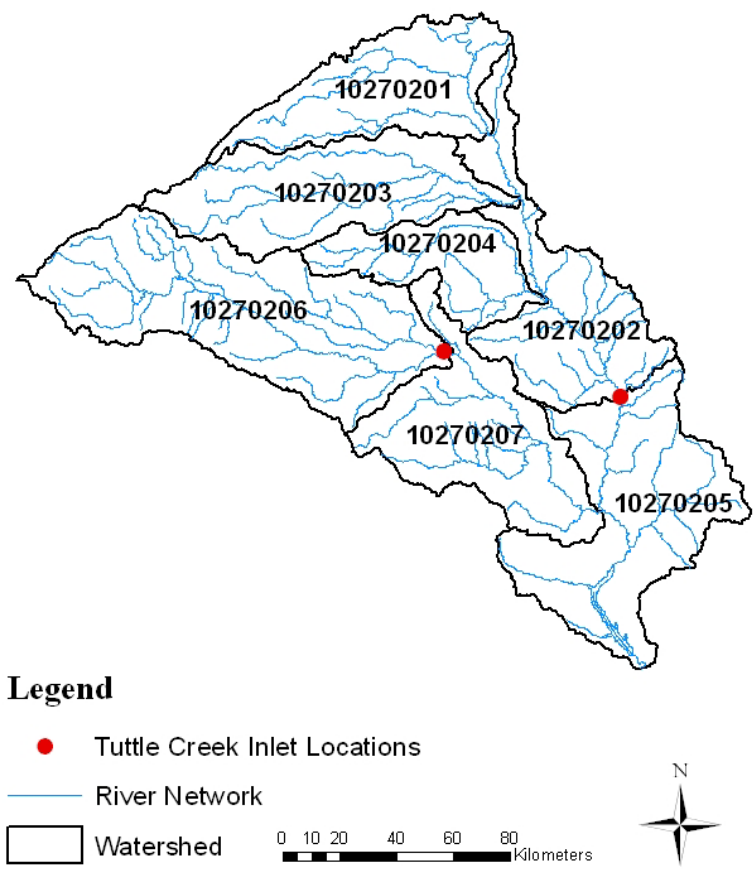


Figure 24 TCL inlets

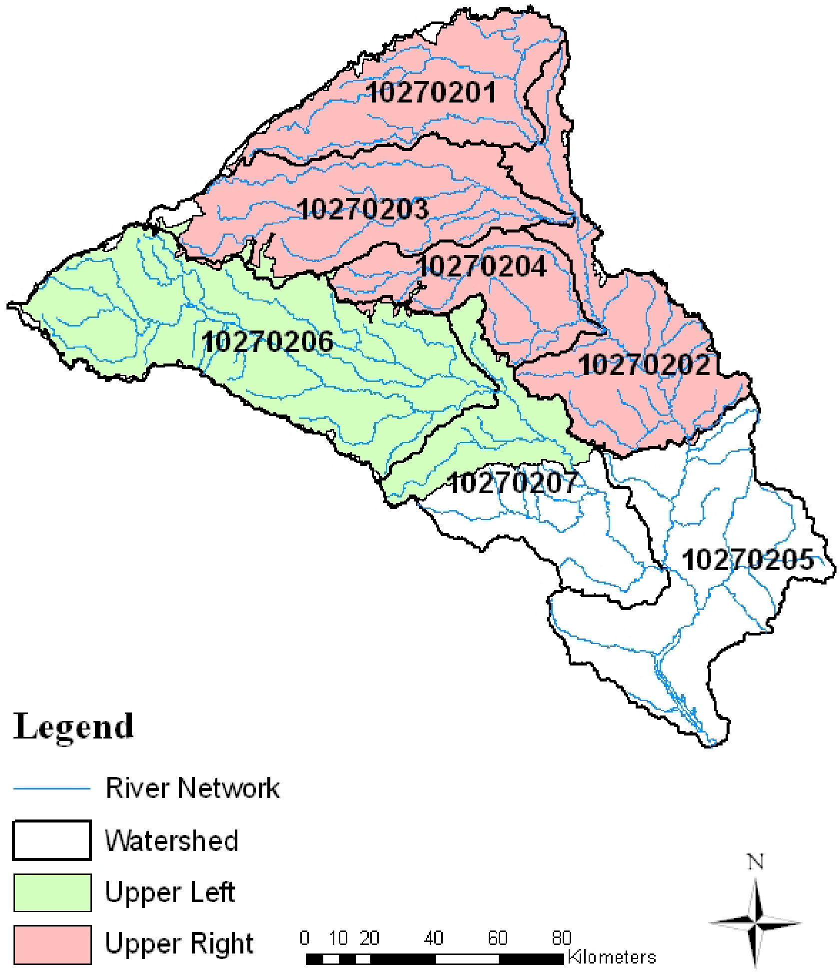


Figure 25 Upper left and upper right watersheds

Model Setup

The following datasets were required to set up the watershed models in SWAT:

- Land use: National Land Cover Database 2001 (NLCD 2001)
- Soils: State Soil Geographic Database (STATSGO)
- Topography: USGS 90-meter Digital Elevation Model (DEM)
- River Network: Environmental Protection Agency (EPA) Reach File Version 1.0
- Weather: National Climatic Data Center (NCDC) weather stations

Identifying the calibration and validation period

There is need to identify at least one dry climatological period and one wet climatological period for the model setup and calibration. Precipitation from 24 weather stations over 31 years were used to estimate average annual precipitation shown in Figure 26. The period of 1998-2002 was selected for model calibration and validation; data from 1997 was used for model warm-up.

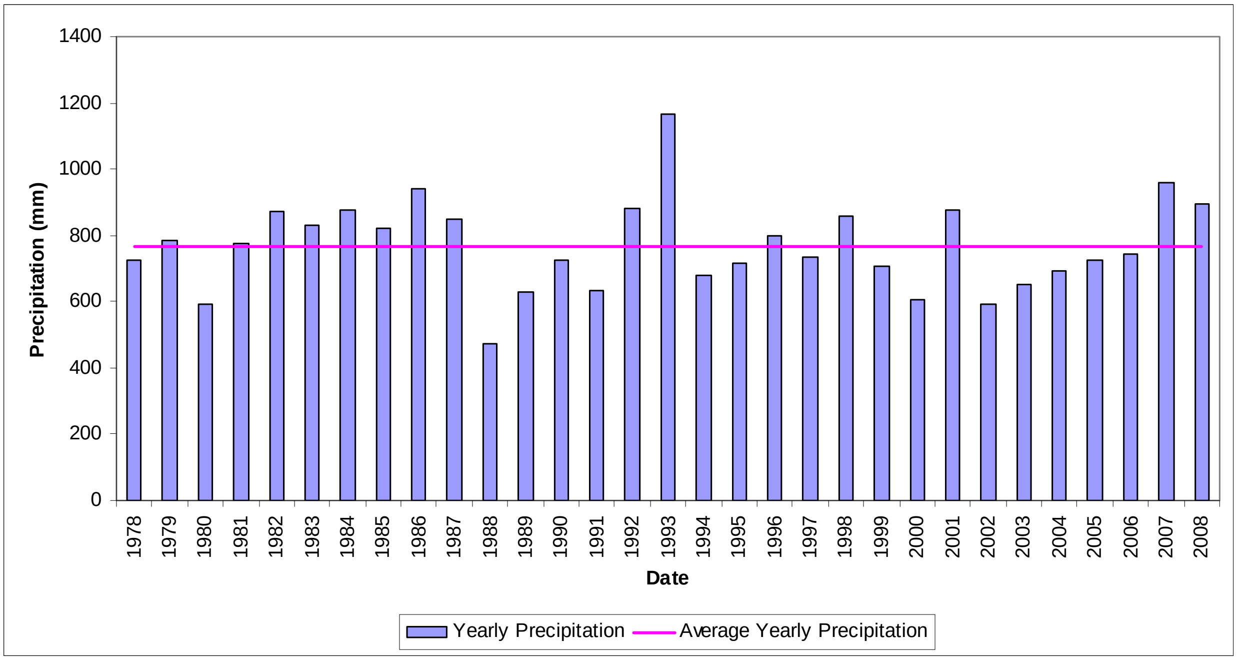


Figure 26 Annual precipitation for the Big Blue watershed

Sensitivity Analysis

A sensitivity analysis was performed and the following parameters were identified and ranked as most sensitive in the study area (Table 16 and Table 17).

Table 16 Sensitivity analysis for flow

Parameter	**Rank**
Initial SCS CN II value	1
Soil evaporation compensation factor	2
Available water capacity	3
Baseflow alpha factor	4
Maximum potential leaf area index	5
Soil depth	6
Surface runoff lag time	7
Channel effective hydraulic conductivity	8
Maximum canopy storage	9
Deep aquifer percolation fraction	10

Table 17 Sensitivity analysis for sediment

Parameter	**Rank**
Lin. re-entrainment parameter for channel sediment routing	1

Manning's n value for main channel	2
Surface runoff lag time	3
Exp. re-entrainment parameter for channel sediment routing	4
Initial SCS CN II value	5
Channel effective hydraulic conductivity	6
Maximum potential leaf area index	7
Soil evaporation compensation factor	8
USLE support practice factor	9
Minimum USLE cover factor	10

Upper Right Calibration

The model was set up based on 31 years (1978-2008) of climatological data from 15 stations in this watershed (Figure 27). Observed streamflow discharge and total suspended solids (TSS) concentration were obtained from the USGS station 06882000 (Big Blue River at Barneston, NE Figure 28). The results of observed vs. uncalibrated and calibrated model output are shown in Figures 6, 7, 8, 9, 10, 11, 12, and 13. Statistical analysis and model performance before and after calibration are shown in Table 18 and Table 19.

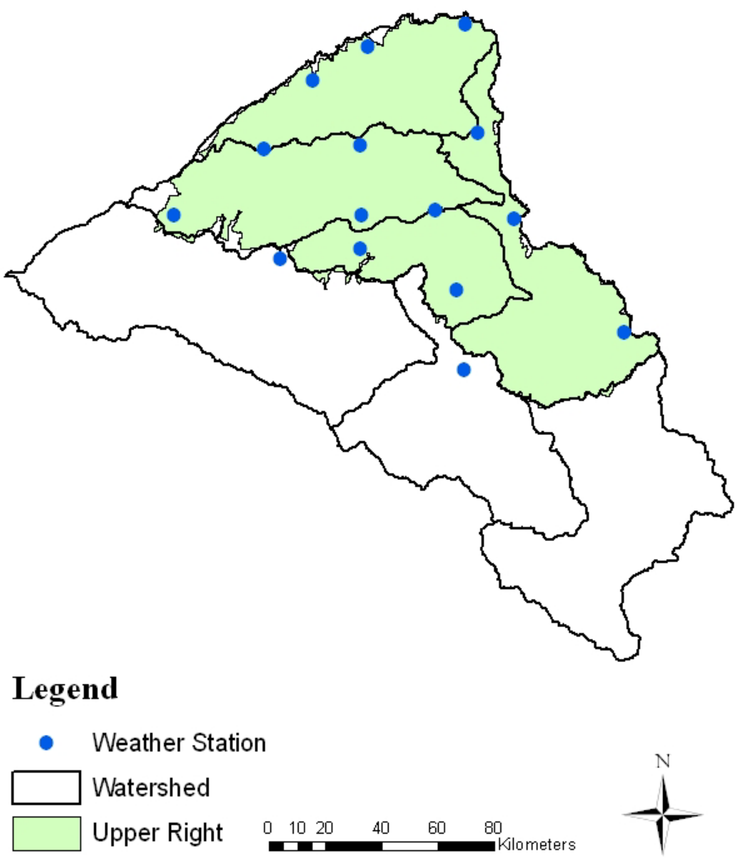


Figure 27 Upper right weather stations

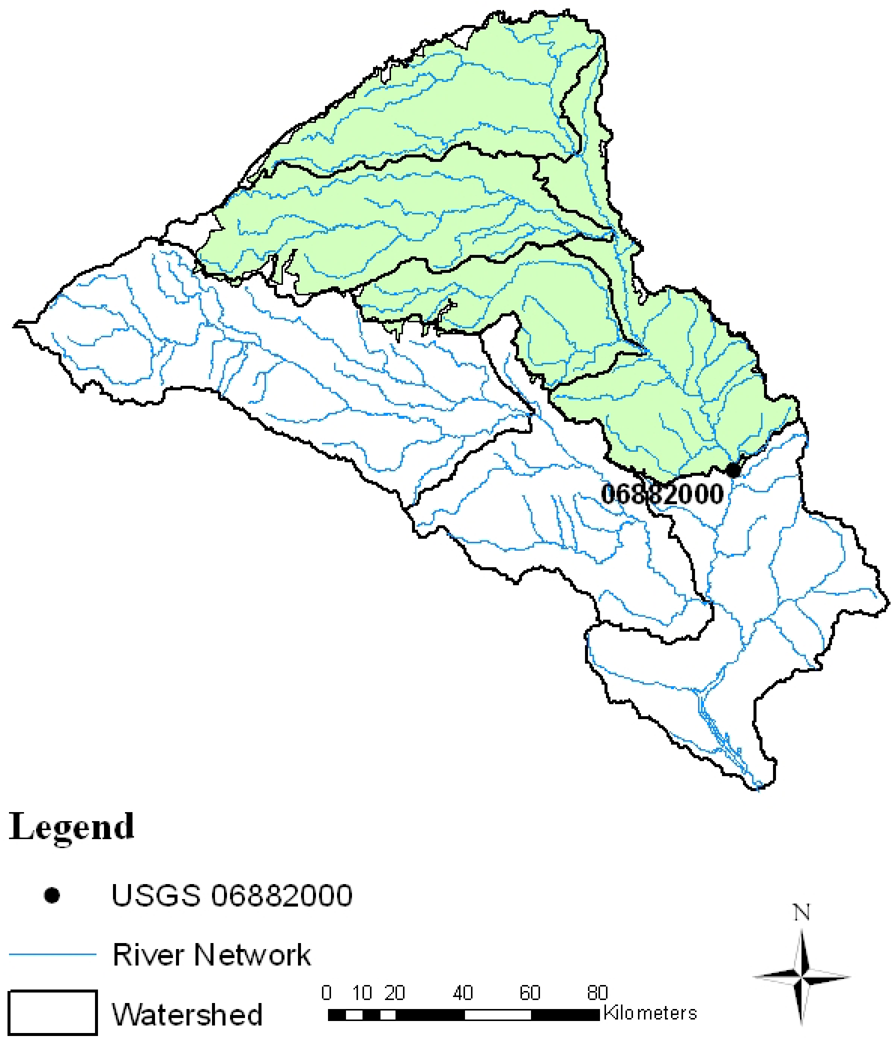


Figure 28 Calibration point for USGS 06882000

Uncalibrated Flow – Upper Right

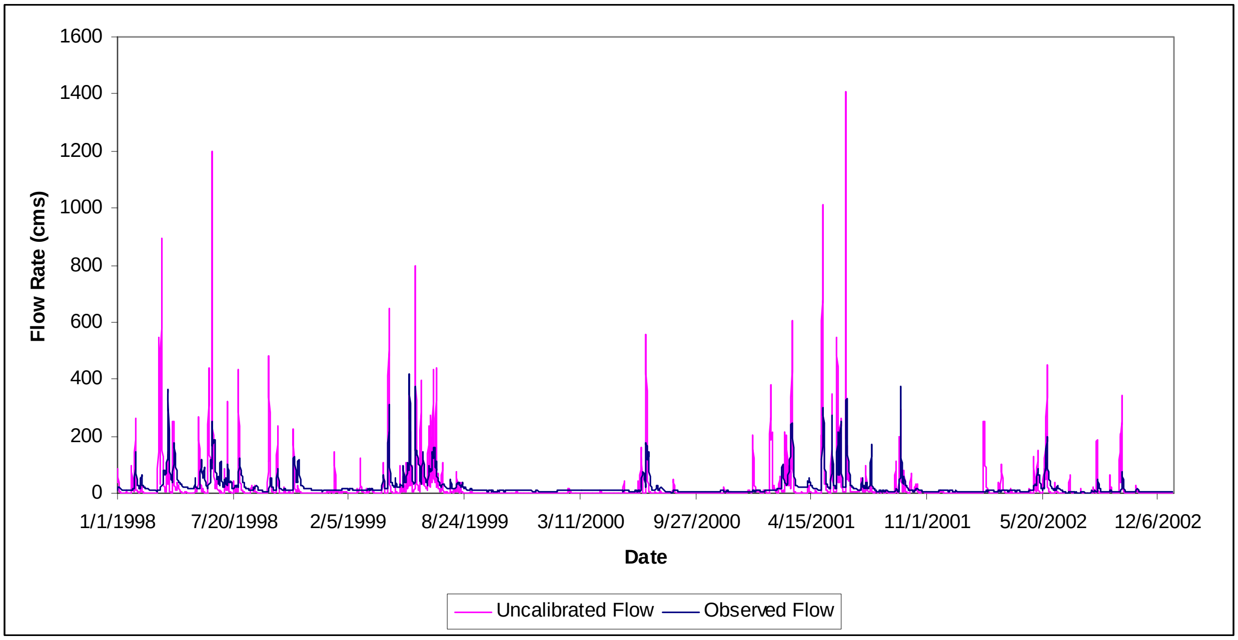


Figure 29 Uncalibrated flow for USGS 06882000

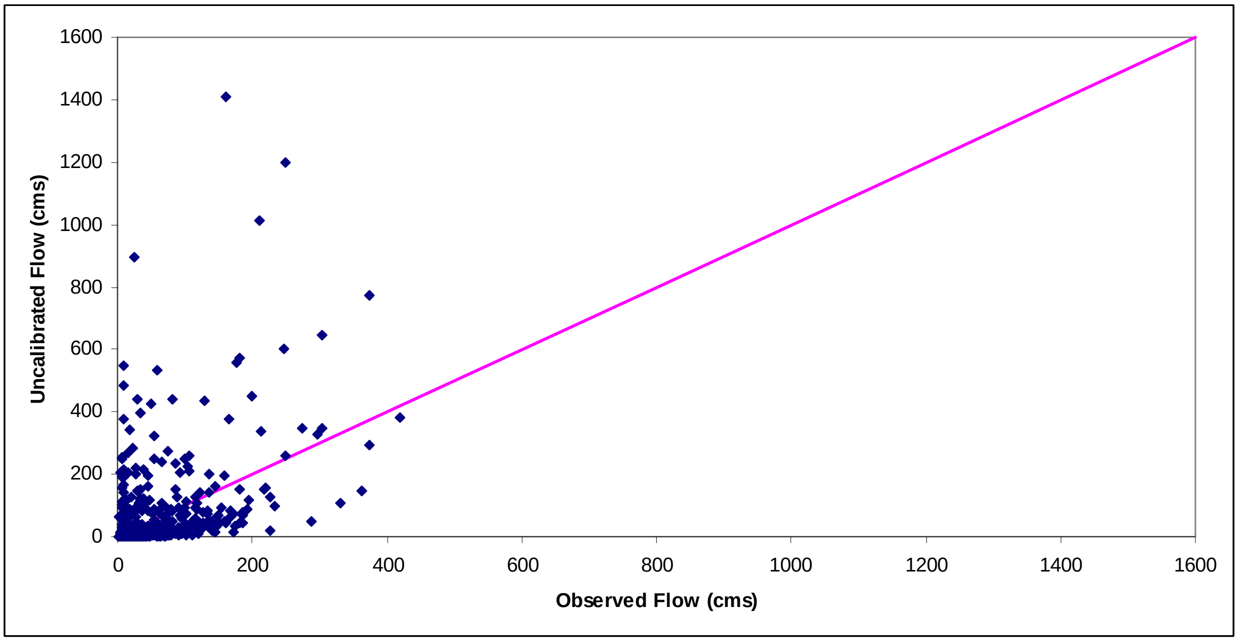


Figure 30 Observed vs. uncalibrated flow for USGS 06882000

Calibrated Flow – Upper Right

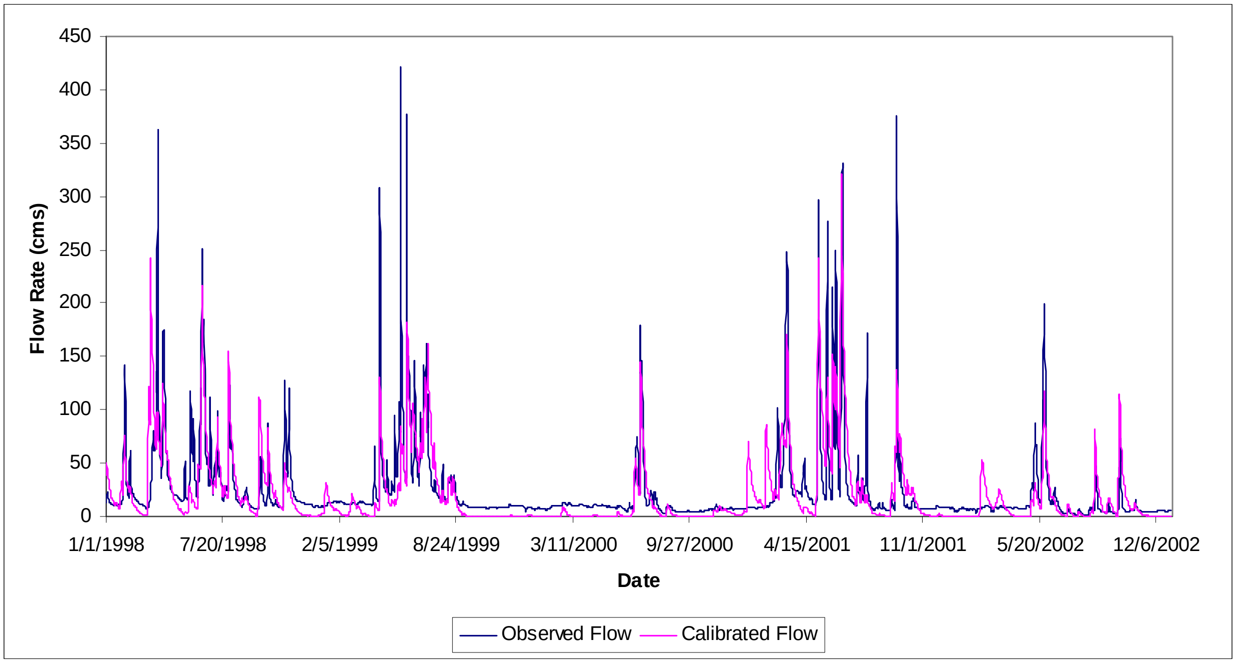


Figure 31 Calibrated flow for USGS 06882000

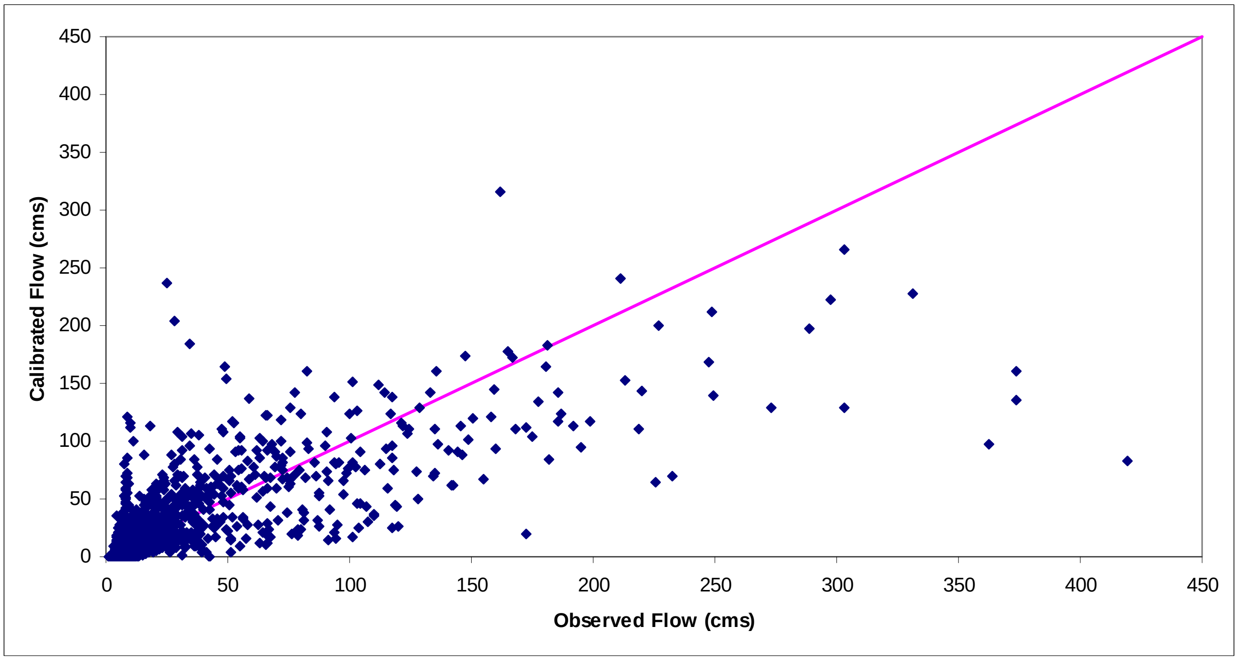


Figure 32 Observed vs. calibrated flow for USGS 06882000

Uncalibrated Sediment – Upper Right

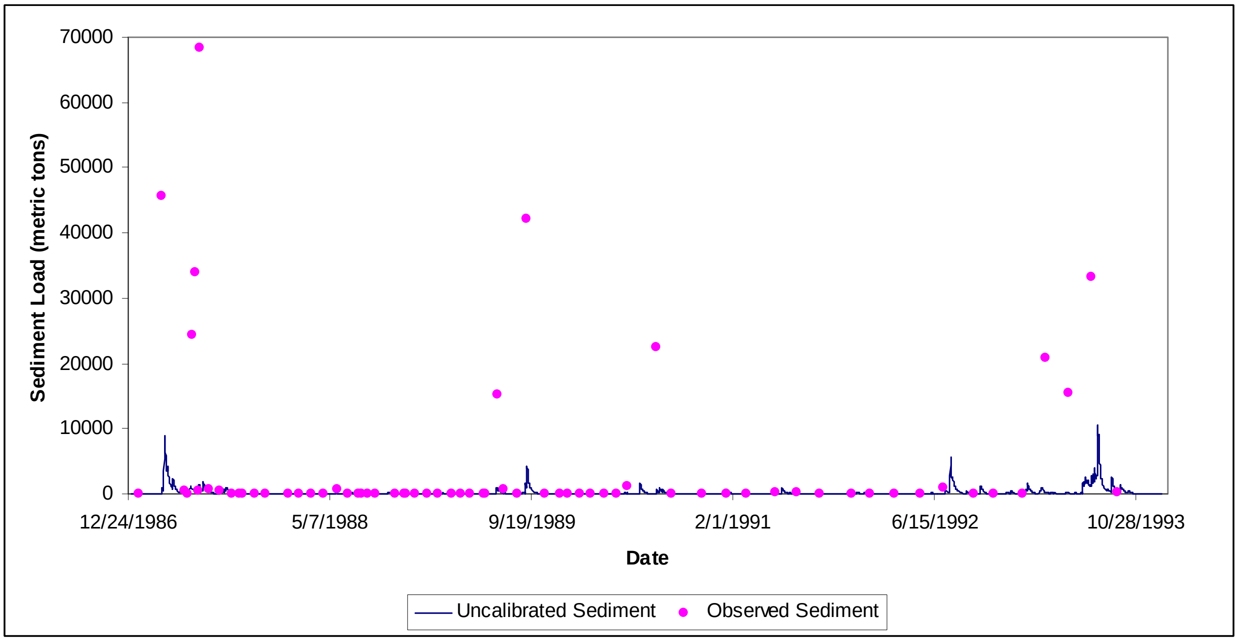


Figure 33 Uncalibrated sediment for USGS 06882000

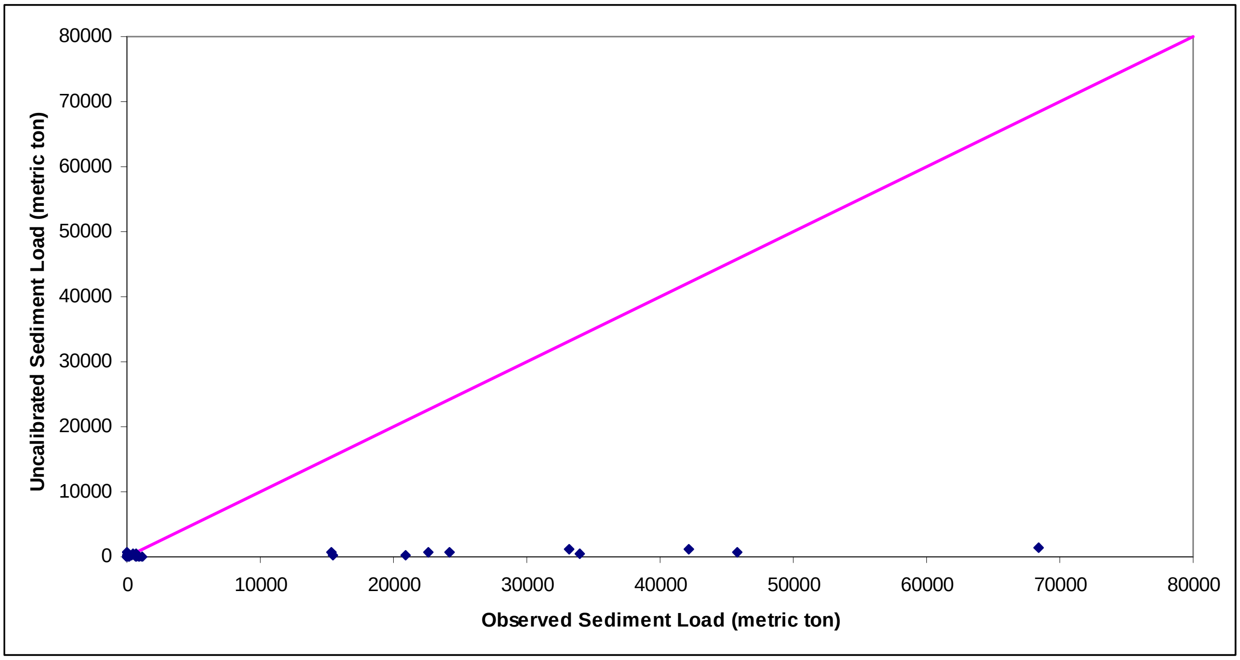


Figure 34 Observed vs. uncalibrated sediment for USGS 06882000

Calibrated Sediment – Upper Right

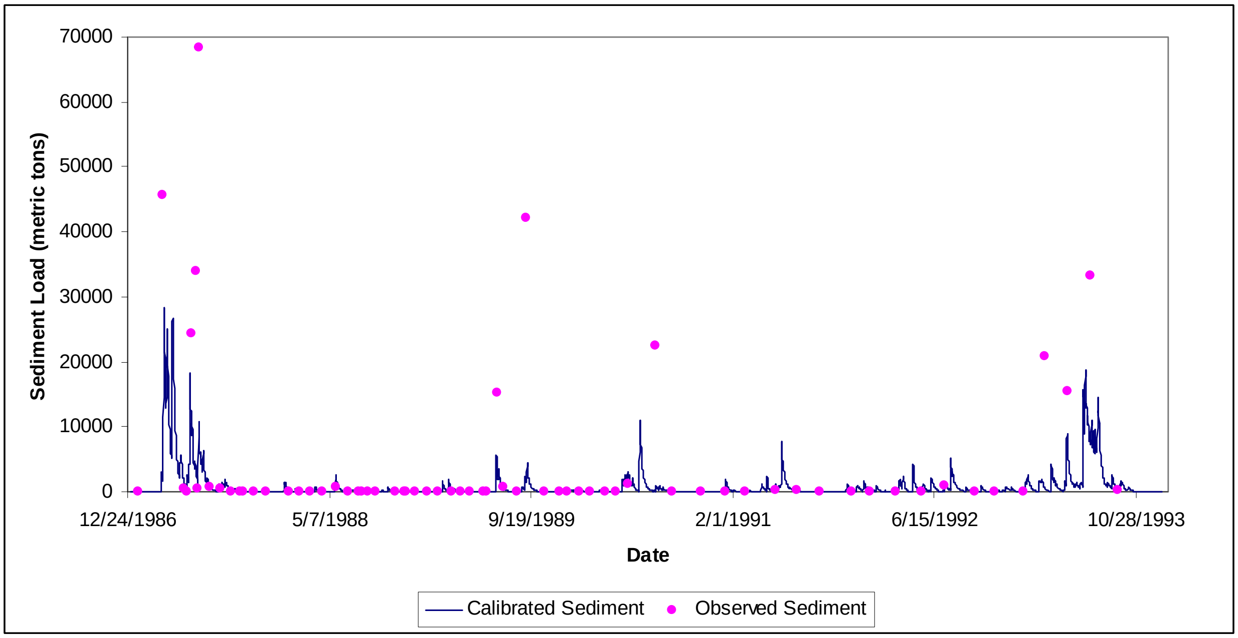


Figure 35 Calibrated sediment for USGS 06882000

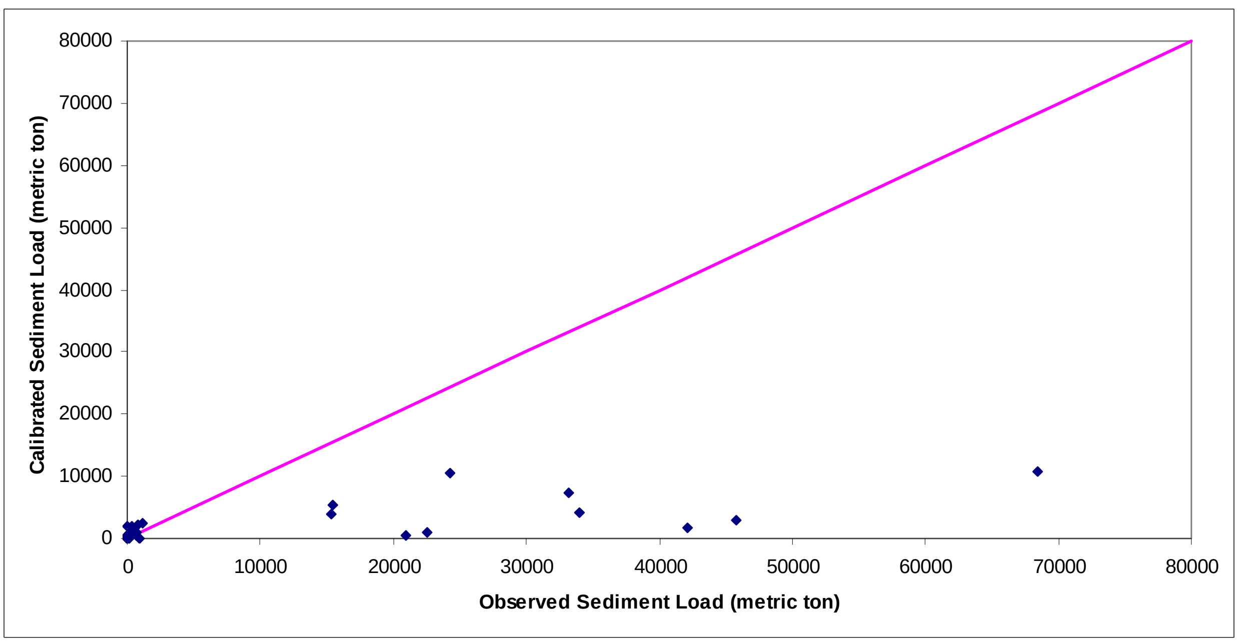


Figure 36 Observed vs. calibrated sediment for USGS 06882000

Calibration Results – Upper Right

Table 18 Uncalibrated results for USGS 06882000

Parameter	Method	Value
Flow (1998-2002)	Nash-Sutcliffe Efficiency	-1.949
	R^2	0.276
	RMSE	69.592
Sediment (1987-1993)	Nash-Sutcliffe Efficiency	-0.003
	R^2	0.702
	RMSE	13423.647

Table 19 Calibration results for USGS 06882000

Parameter	Method	Value
Flow (1998-2002)	Nash-Sutcliffe Efficiency	0.552
	R^2	0.570
	RMSE	27.112
Sediment (1987-1993)	Nash-Sutcliffe Efficiency	0.138
	R^2	0.589
	RMSE	11928.647

Upper Left Calibration

The model was set up based on 31 years (1978-2008) of climatological data from 12 stations in this watershed (Figure 37). Observed streamflow discharge was obtained from the USGS station 06884025 (Little Blue River at Hollenberg, KS), while total suspended solids (TSS) concentration was obtained from Kansas Department of Health and Environment sampling point 000232 (Little Blue River near Hollenberg, KS), shown in Figure 38. The results of observed vs. uncalibrated and calibrated model output are shown in Figure 39 through Figure 46. Statistical analysis and model performance before and after calibration are shown in Table 20 and Table 21.

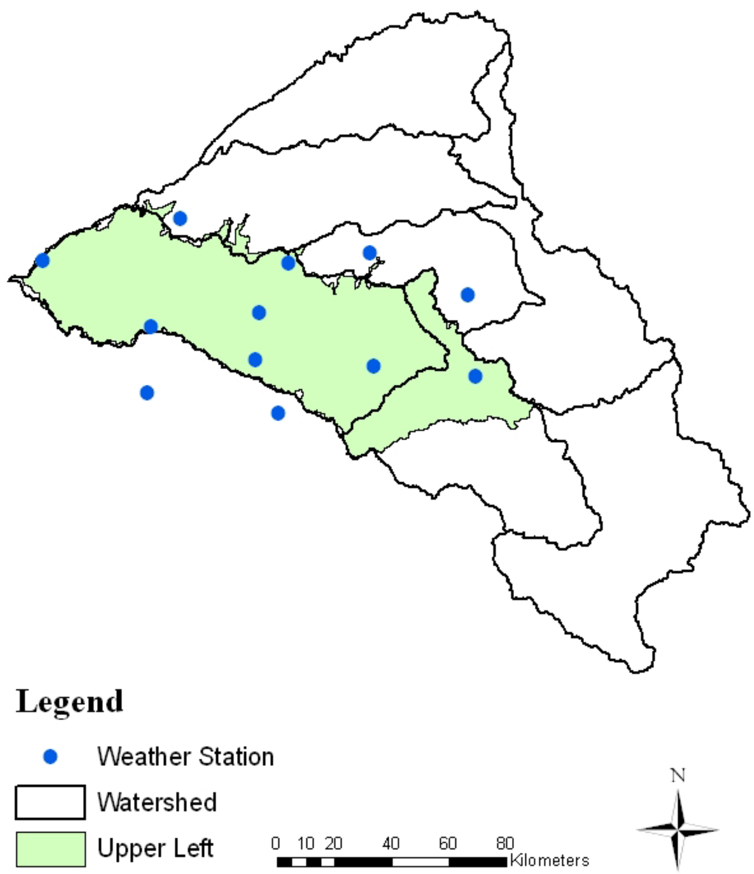


Figure 37 Upper left weather stations

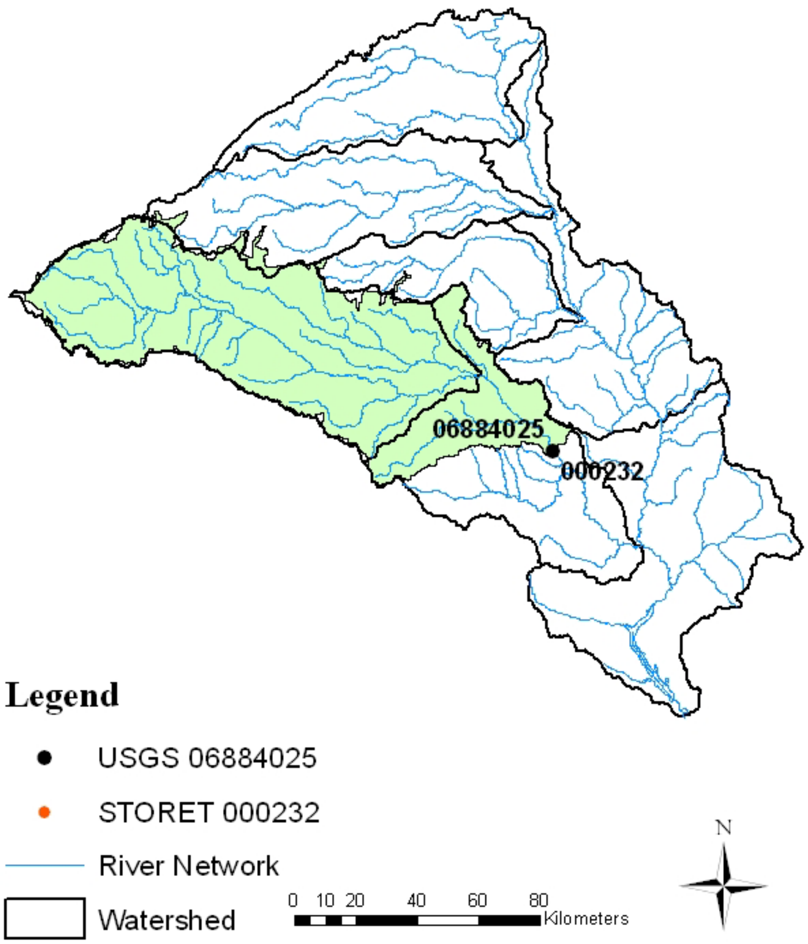


Figure 38 Calibration point for USGS 06884025 and STORET 000232

Uncalibrated Flow – Upper Left

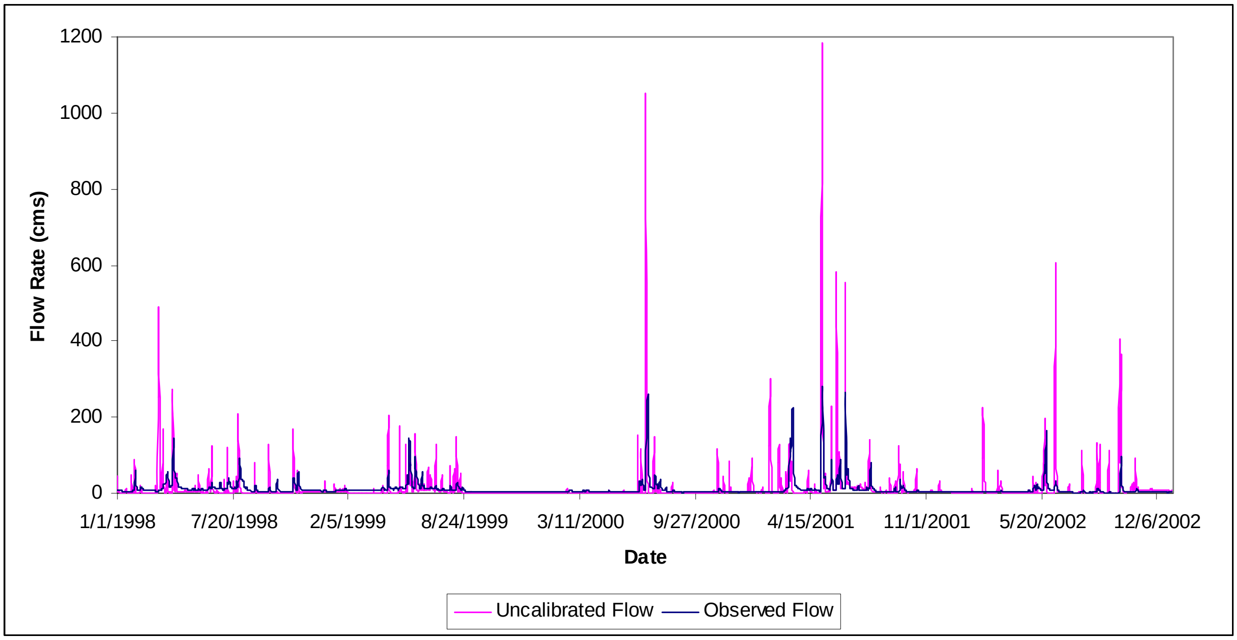


Figure 39 Uncalibrated flow for USGS 06884025

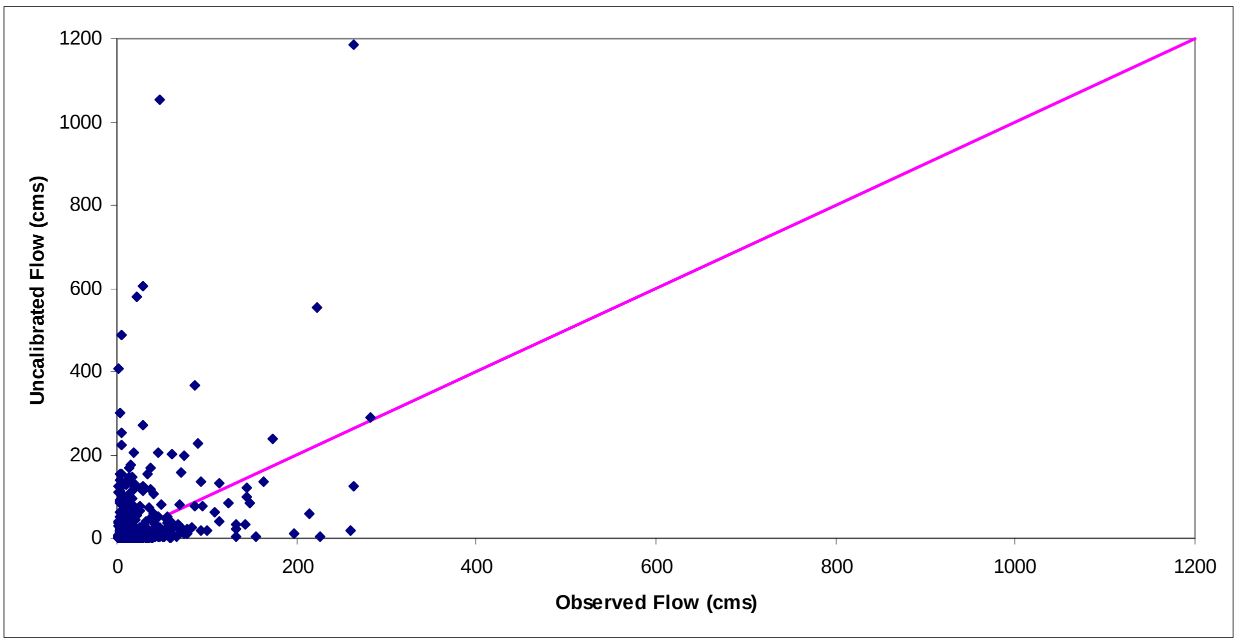


Figure 40 Observed vs. uncalibrated flow for USGS 06884025

Calibrated Flow – Upper Left

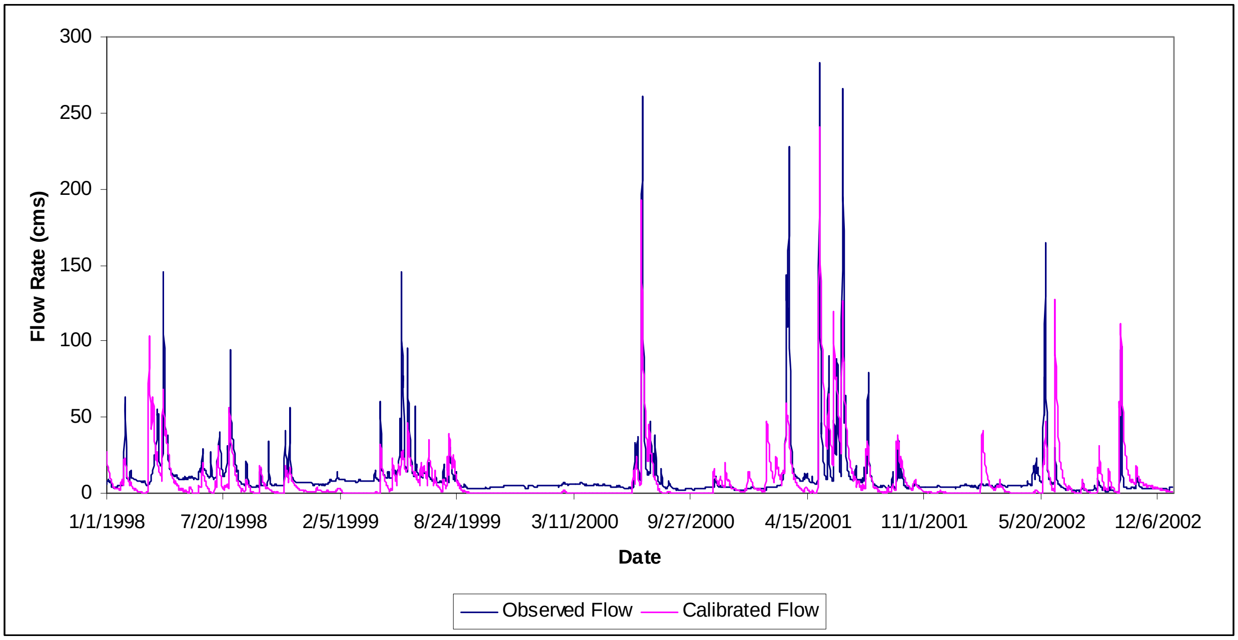


Figure 41 Calibrated flow for USGS 06884025

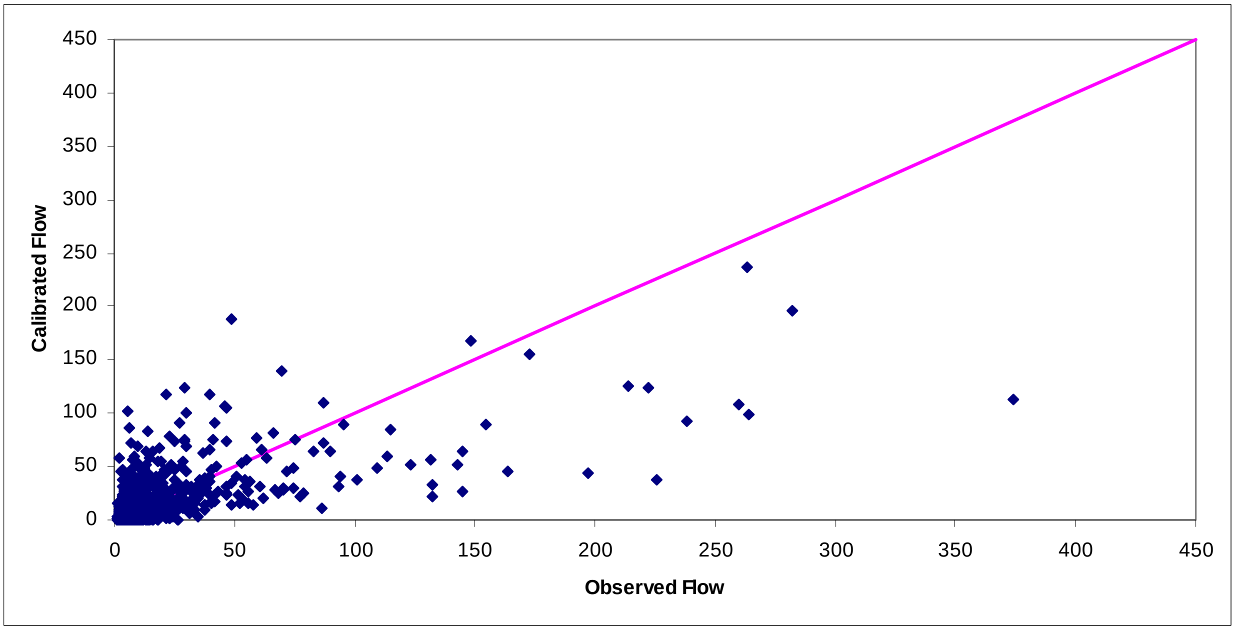


Figure 42 Observed vs. calibrated flow for USGS 06884025

Uncalibrated Sediment – Upper Left

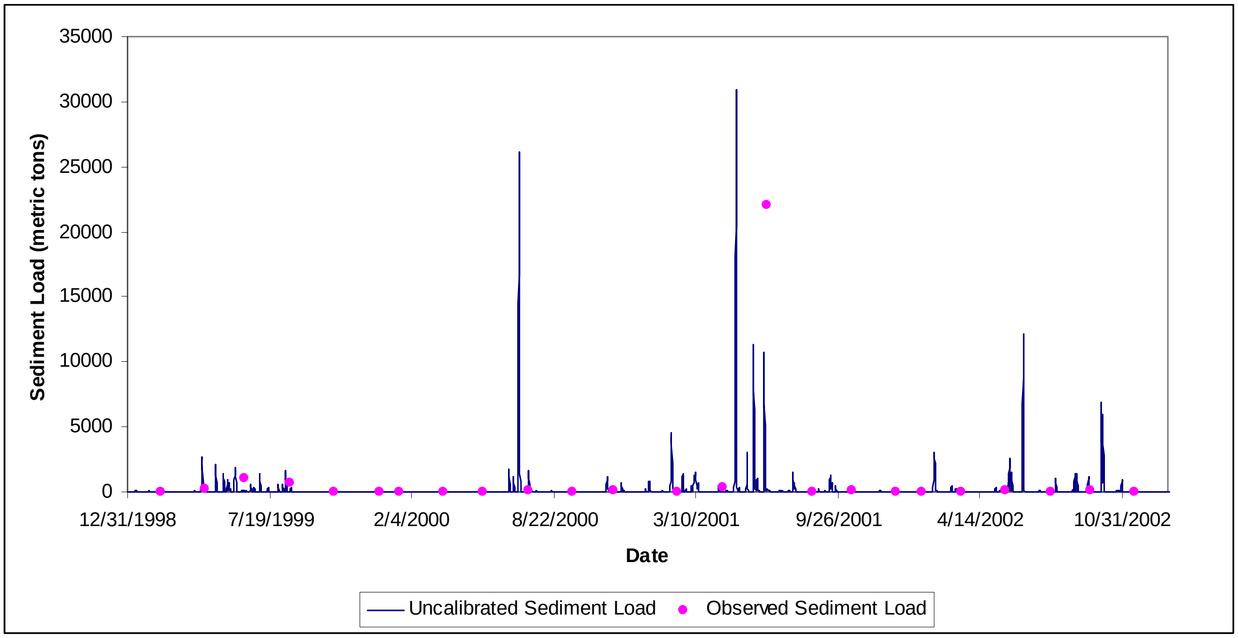


Figure 43 Uncalibrated sediment load for STORET 000232

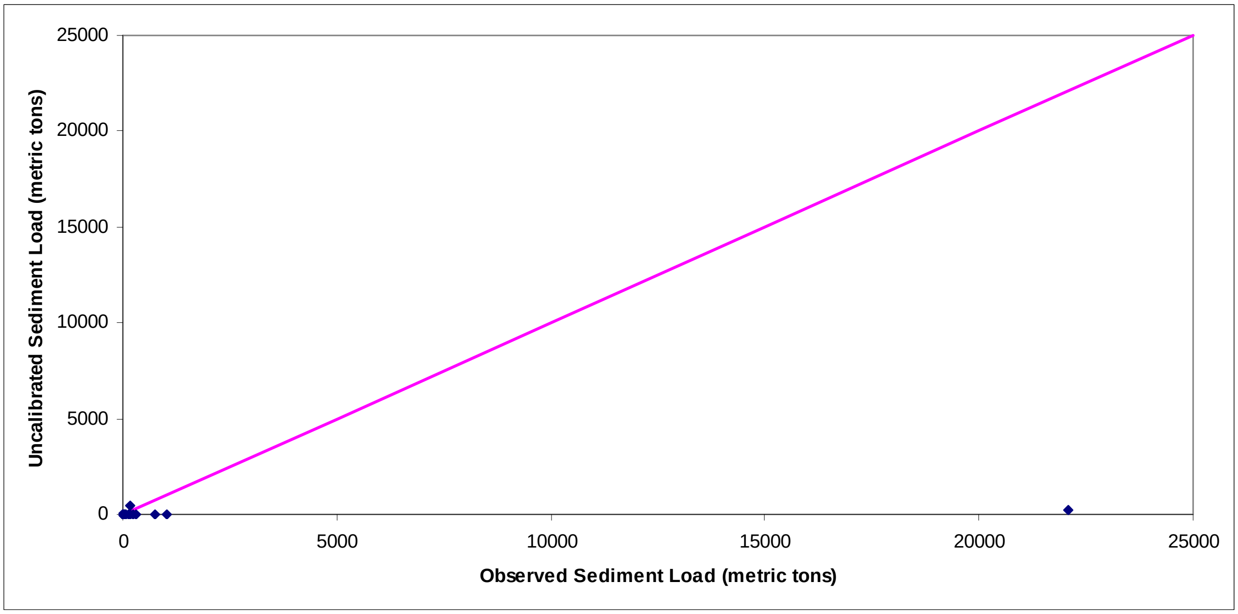


Figure 44 Observed vs. uncalibrated sediment load for STORET 000232

Calibrated Sediment – Upper Left

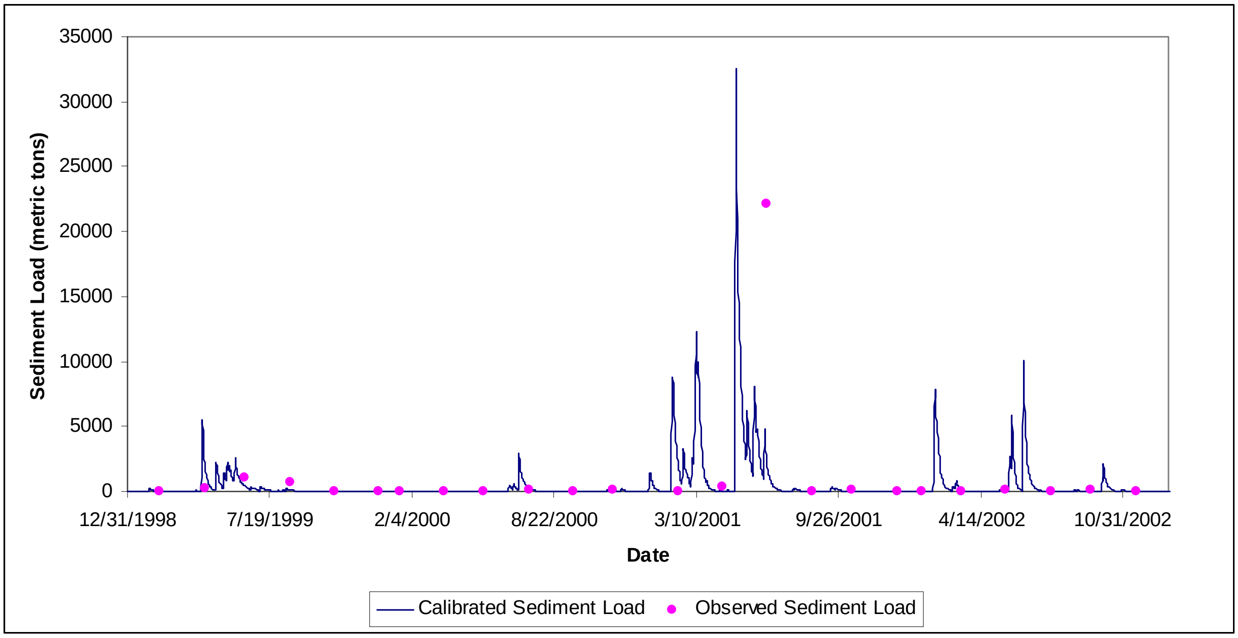


Figure 45 Calibrated sediment load for STORET 000232

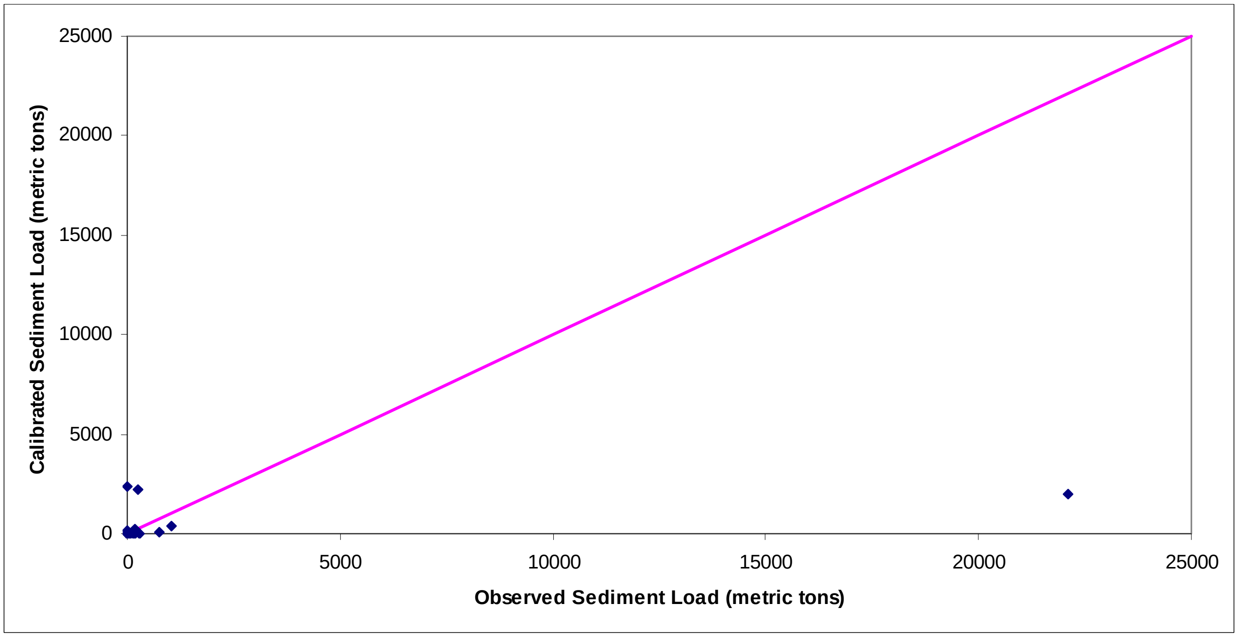


Figure 46 Observed vs. calibrated sediment for STORET 000232

Calibration Results – Upper Left

Table 20 Uncalibrated results for USGS 06884025 and STORET 000232

Parameter	Method	Value
Flow (1998-2002)	Nash-Sutcliffe Efficiency	-4.041
	R^2	0.172
	RMSE	49.683
Sediment (1999-2002)	Nash-Sutcliffe Efficiency	-0.037
	R^2	0.131
	RMSE	4473.263

Table 21 Calibration results for USGS 06884025 and STORET 000232

Parameter	Method	Value
Flow (1998-2002)	Nash-Sutcliffe Efficiency	0.436
	R^2	0.465
	RMSE	16.612
Sediment (1999-2002)	Nash-Sutcliffe Efficiency	0.104
	R^2	0.240
	RMSE	4157.985

TCL watershed Calibration

The model was set up based on 31 years (1978-2008) of climatological data from 9 stations in this watershed (Figure 47). Observed streamflow discharge was obtained from the US Corps of Engineering station (upstream of TCL), while total suspended solids (TSS) concentration was obtained from Kansas Department of Health and Environment sampling point 000240 shown in Figure 48. Calibration for TCL was completed using SWAT2009. The results of observed vs. uncalibrated and calibrated model output are shown in Figure 49 through Figure 56. Statistical analysis and model performance before and after calibration are shown in Table 22 through Table 25.

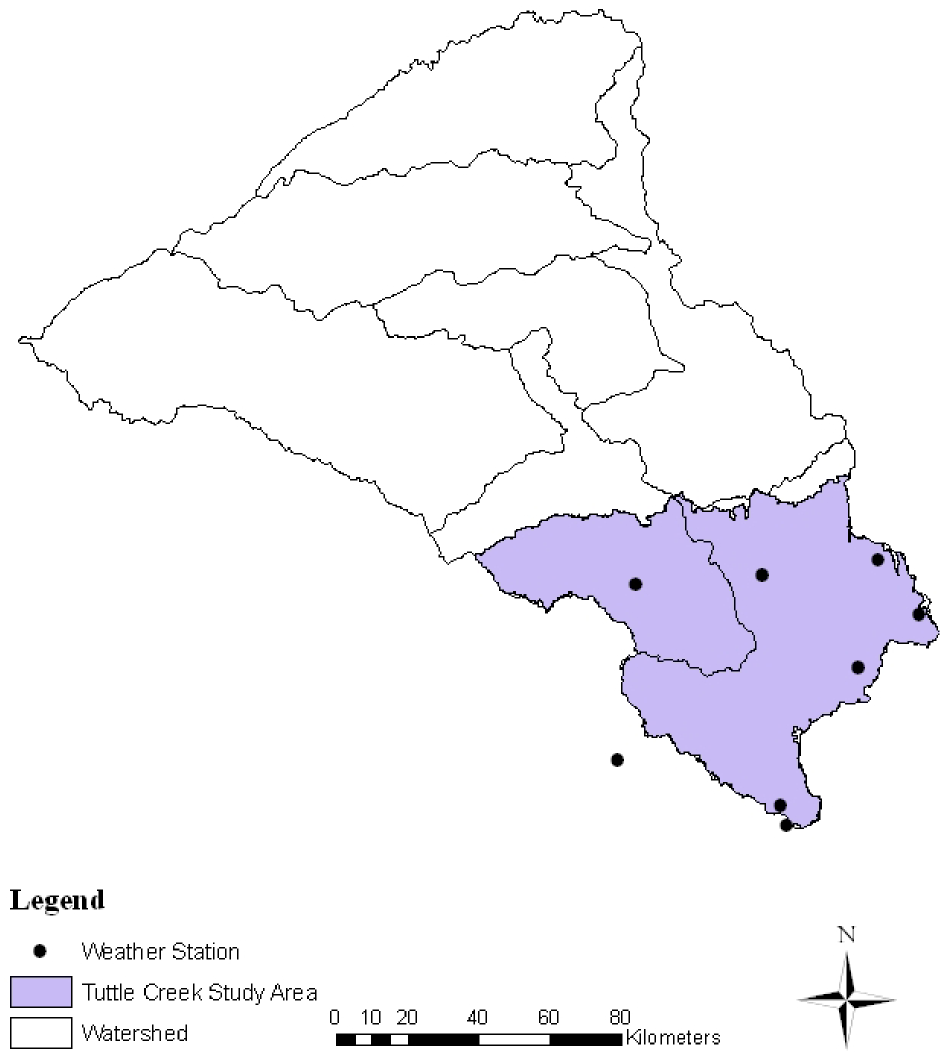


Figure 47 TCL weather stations

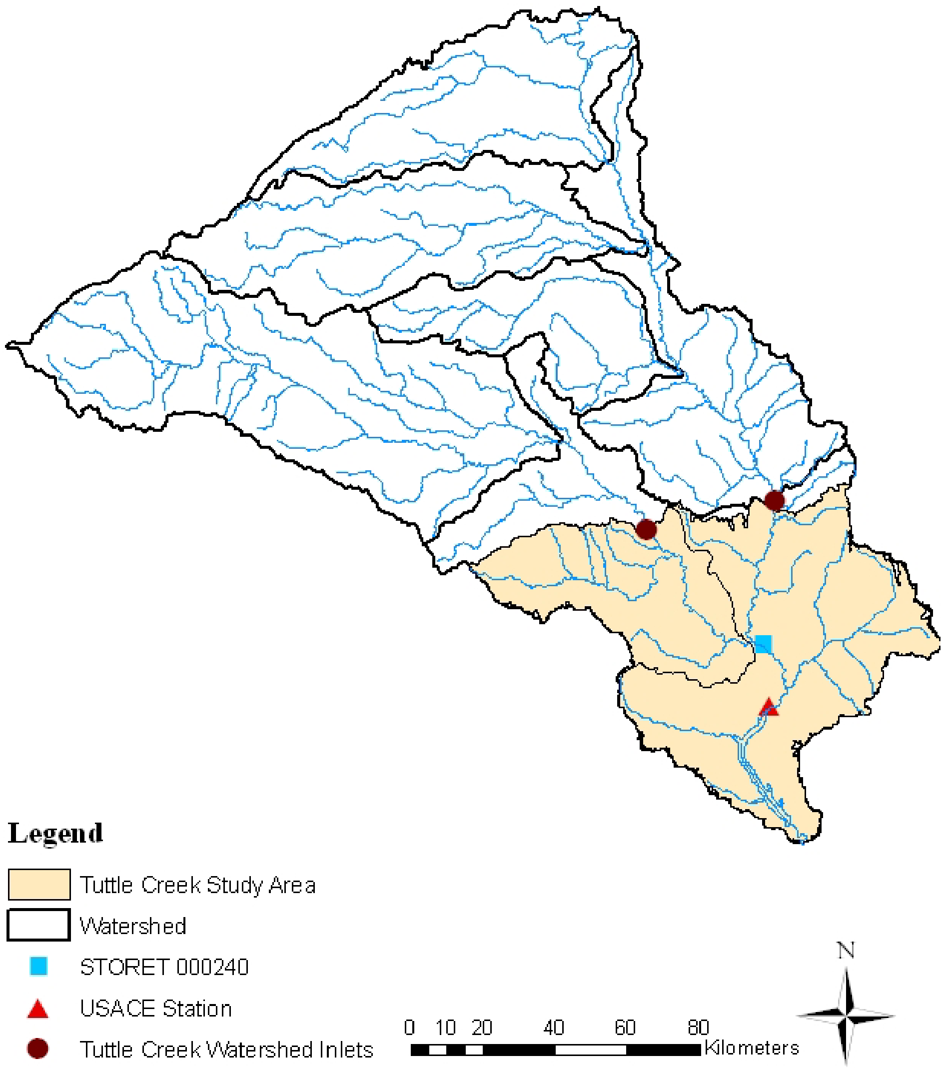


Figure 48 TCL watershed

Uncalibrated Flow – TCL

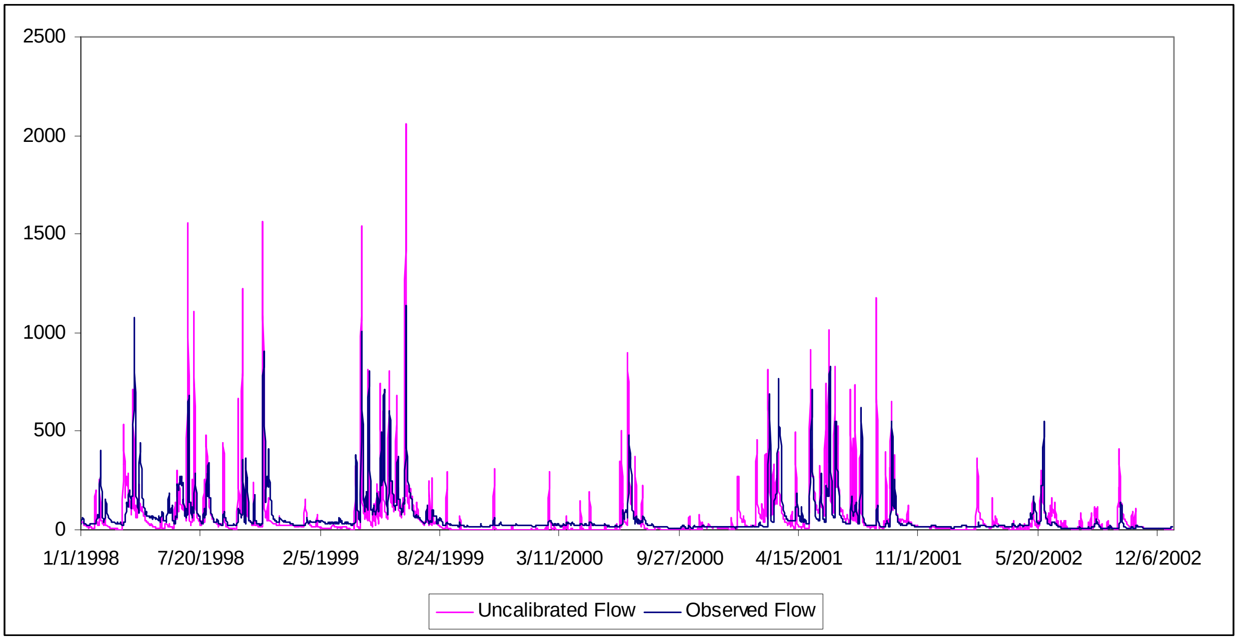


Figure 49 Uncalibrated flow for US Corp of Engineering station at the inlet of TCL

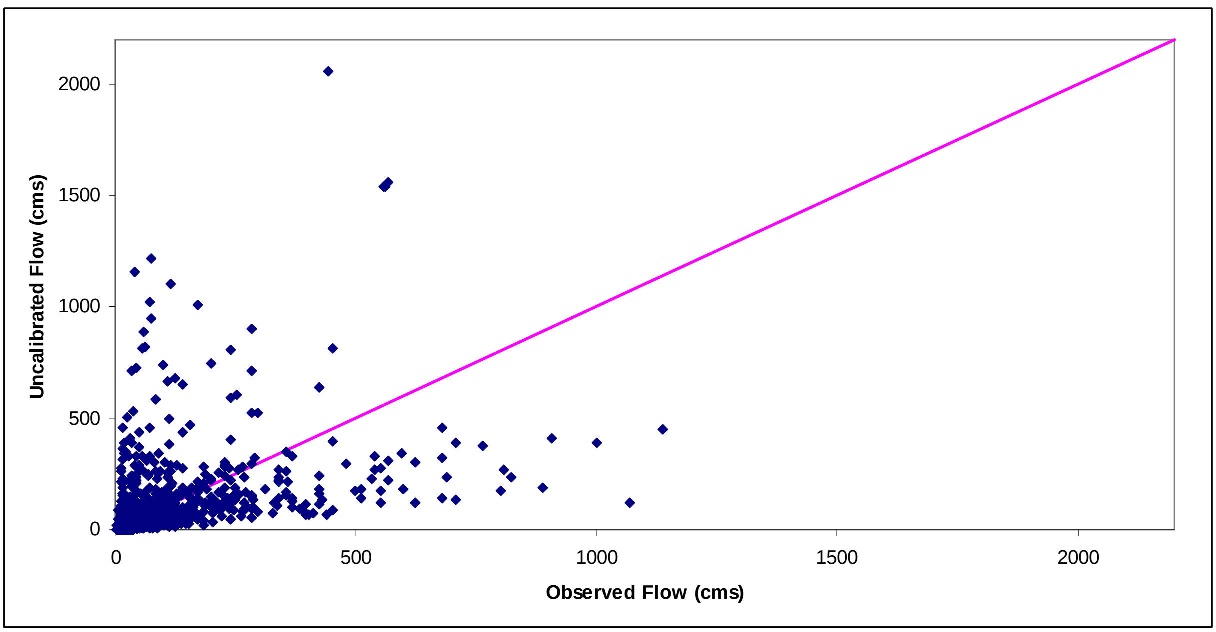


Figure 50 Observed vs. uncalibrated flow for US Corp of Engineering station at the inlet of TCL

Calibrated Flow – TCL

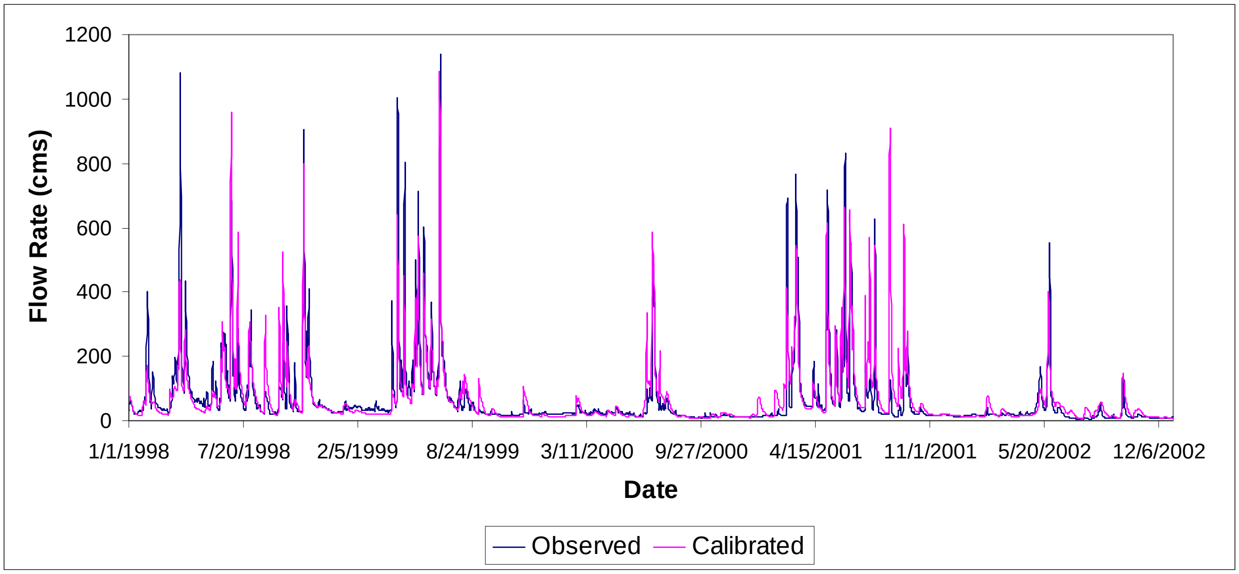


Figure 51 Calibrated flow for US Corp of Engineering station at the inlet of TCL

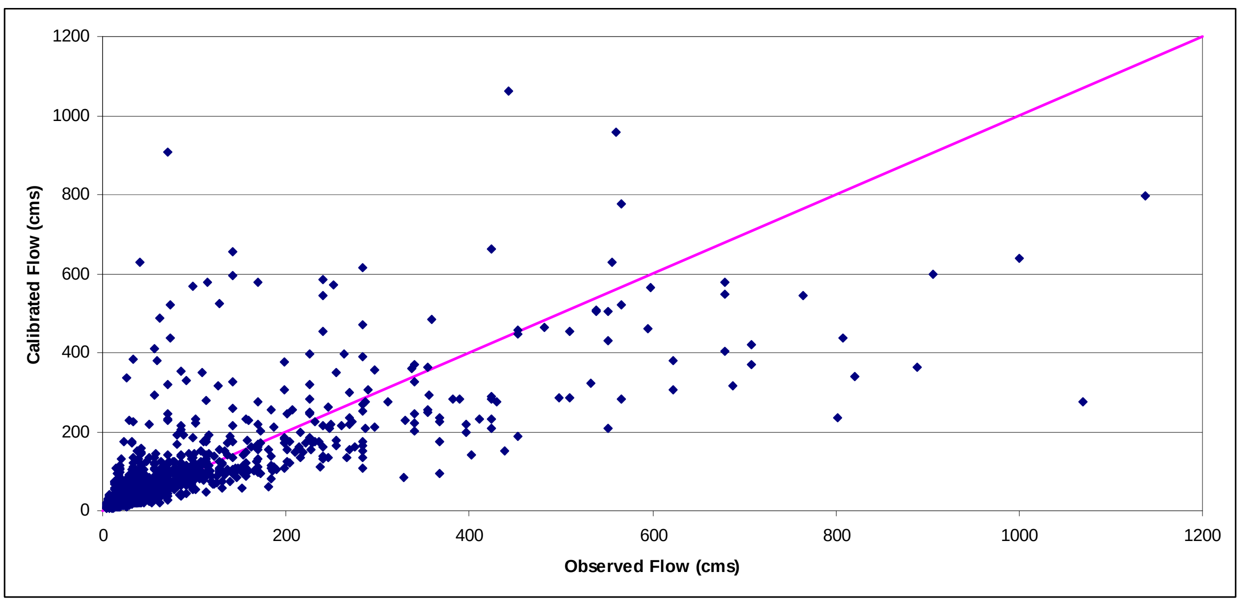


Figure 52 Observed vs. calibrated flow for US Corp of Engineering station at the inlet of TCL

Uncalibrated Sediment – TCL

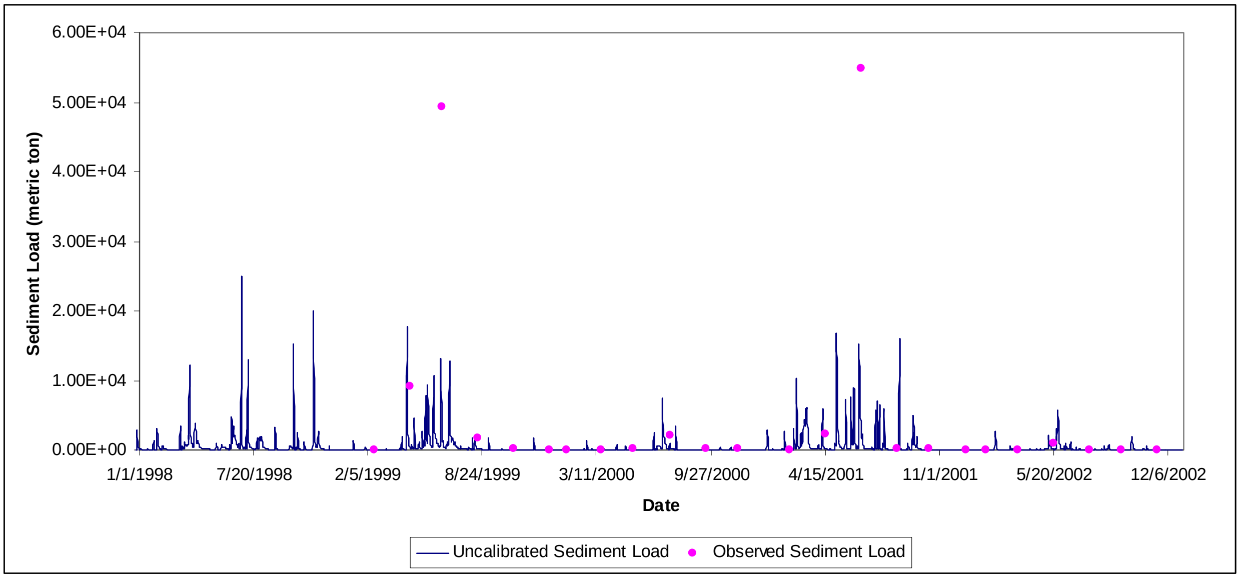


Figure 53 Uncalibrated sediment load for STORET 000240

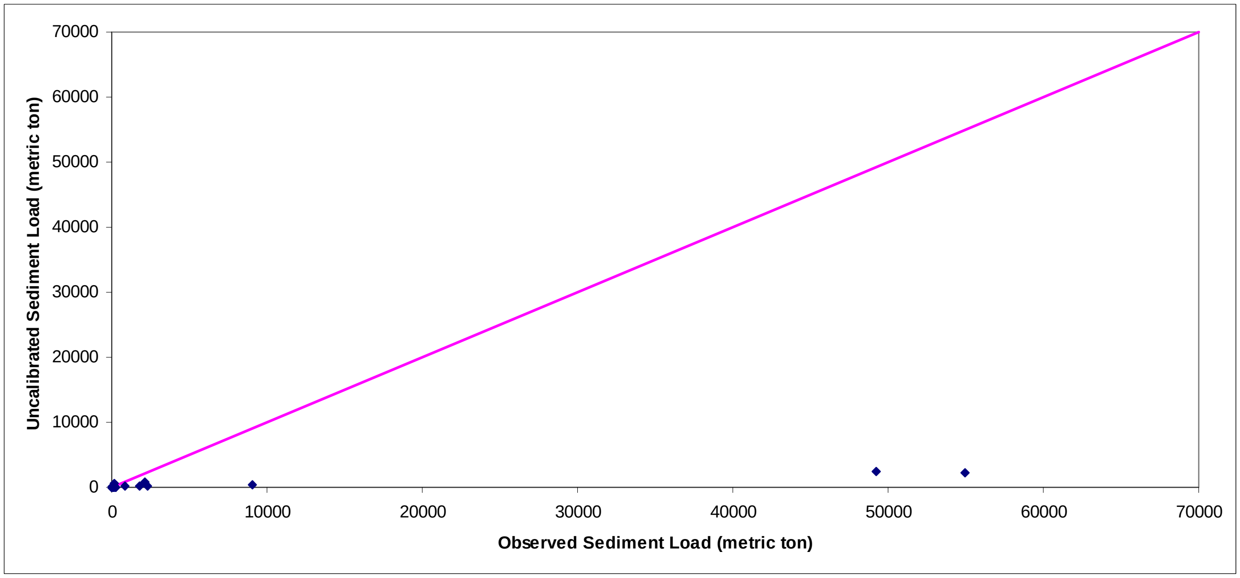


Figure 54 Observed vs. uncalibrated sediment load for STORET 000240

Calibrated Sediment – TCL

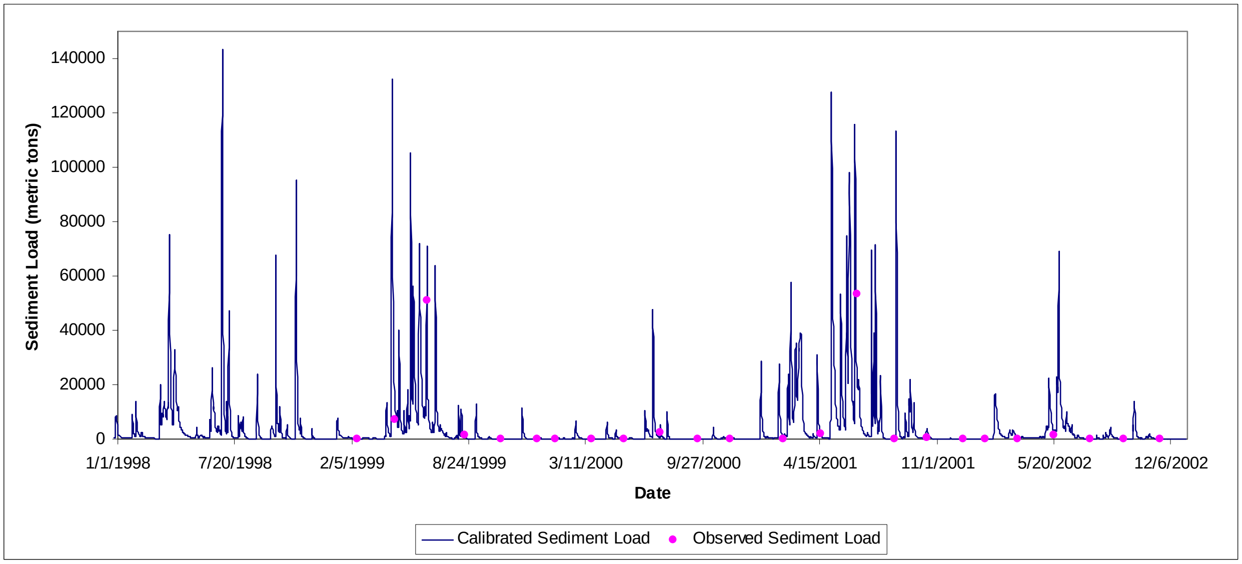


Figure 55 Calibrated sediment load for STORET 000240

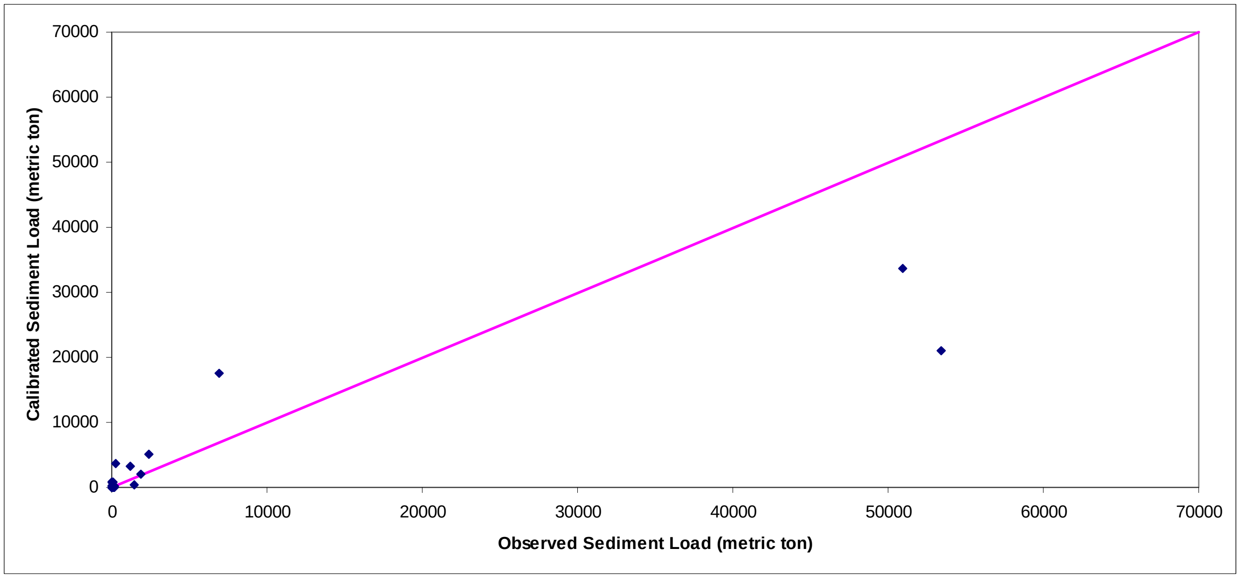


Figure 56 Observed vs. calibrated sediment load for STORET 000240

Table 22 Uncalibrated results for US Corp of Engineering station at the inlet of TCL

Parameter	Method	Value
Flow (1998-2002)	Nash-Sutcliffe Efficiency	-0.425
	R^2	0.217
	RMSE	133.113

Table 23 Uncalibrated Results for STORET 000240

Parameter	Method	Value
Sediment (1999-2002)	Nash-Sutcliffe Efficiency	-0.026
	R^2	0.921
	RMSE	14504.996

Table 24 Calibration Results for US Corp of Engineering Station at the inlet of TCL

Parameter	Method	Calibration (1998-2000)	Validation (2001-2002)	Combined (1998-2002)
Flow	Nash-Sutcliffe Efficiency	0.640	0.385	0.525
	R^2	0.645	0.505	0.580
	RMSE	69.374	82.448	74.853

Table 25 Calibration Results for STORET 000240

Parameter	Method	Calibration (1999-2000)	Validation (2001-2002)	Combined (1999-2002)
Sediment	Nash-Sutcliffe Efficiency	0.819	0.587	0.697
	R^2	0.866	0.961	0.814
	RMSE	5925.511	9438.760	7880.414

Results

Estimate Annual Sediment Deposition and Yield under Current and BMP Scenarios (Support Objective 2 and 5)

Three BMPs (filter strips, native grass, and no-till) were tested and compared to a base scenario with no practice application. Each BMP was applied to all available agricultural land for each scenario. IN all three cases, the BMPs demonstrate reduction from the no BMP scenario at both the subbasin level and at the inlet to TCL. Annual average subbasin-level sediment yield for all four scenarios is presented in Table 26. Annual average sediment load entering TCL from the Big Blue River (upstream of subbasin 25) and Fancy Creek (subbasin 26) for all four scenarios is presented in Table 27.

Table 26 Annual average subbasin-level sediment yield (1978-2008 average)

Subbasin	No BMP (ton/ha)	Filter Strip (ton/ha)	Native Grass (ton/ha)	No-Till (ton/ha)
1	2.491	0.848	0.353	2.005
2	6.960	2.037	0.566	5.304
3	4.919	1.474	0.482	3.898
4	2.577	0.910	0.393	2.065
5	4.298	1.302	0.409	3.404
6	5.683	1.690	0.525	4.498
7	3.319	1.036	0.348	2.645
8	0.644	0.249	0.121	0.528
9	6.438	1.938	0.666	5.099
10	3.182	1.045	0.383	2.527
11	12.014	3.483	1.025	9.305

12	3.457	1.227	0.550	2.753
13	7.172	2.183	0.605	5.468
14	3.830	1.441	0.732	3.109
15	4.890	1.583	0.599	3.899
16	2.685	1.063	0.576	2.198
17	10.010	3.082	1.018	7.675
18	7.061	2.353	0.901	5.634
19	1.475	1.038	0.906	1.345
20	5.637	1.856	0.657	4.428
21	3.101	1.308	0.756	2.560
22	3.071	1.068	0.455	2.448
23	4.563	1.737	0.928	3.715
24	2.627	1.095	0.608	2.136
25	1.134	0.781	0.668	1.015
26	2.469	0.946	0.444	1.975
27	1.107	0.689	0.556	0.947
28	1.241	0.722	0.544	1.045

Table 27 Annual average sediment load to TCL (1978-2008)

	No BMP	Filter Strip	Native Grass	No-Till
Fancy Creek (tons)	160,700	61,610	28,880	128,600
Big Blue River (tons)	2,905,000	980100	661,700	1,836,000
Total (tons)	3,065,700	1,041,710	690,580	1,964,600

Estimate Annual Sediment Deposition and Yield (Support Objective 2)

High priority areas (subbasins) throughout the watershed are presented in Figure 57. Priority ranking was split into three categories (low, medium, and high) based on sediment yield (tons/ha) using the natural breaks (Jenks) method. In general, the eastern portion of the watershed contains the most high priority areas, while the western and central portions of the watershed are consistently of medium priority.

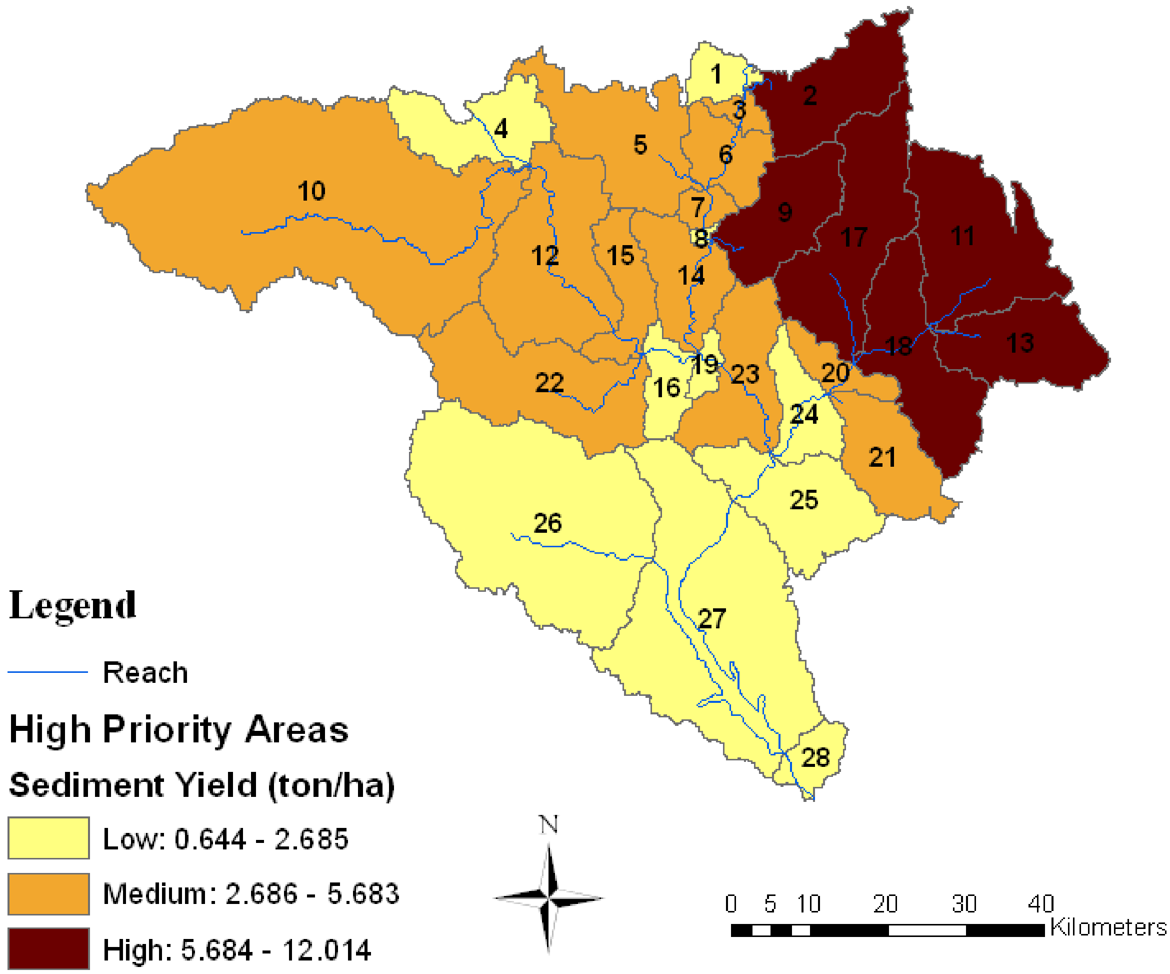


Figure 57 Baseline sediment yield high priority areas for the no BMP scenario

Determine Trends of Constituents (Support Objective 3)

Yearly contributions of sediment (metric tons) from both rivers (Big Blue River and Fancy Creek) entering TCL are presented in Figure 58. The Big Blue River contributes considerably more sediment load than Fancy Creek to the reservoir annually.

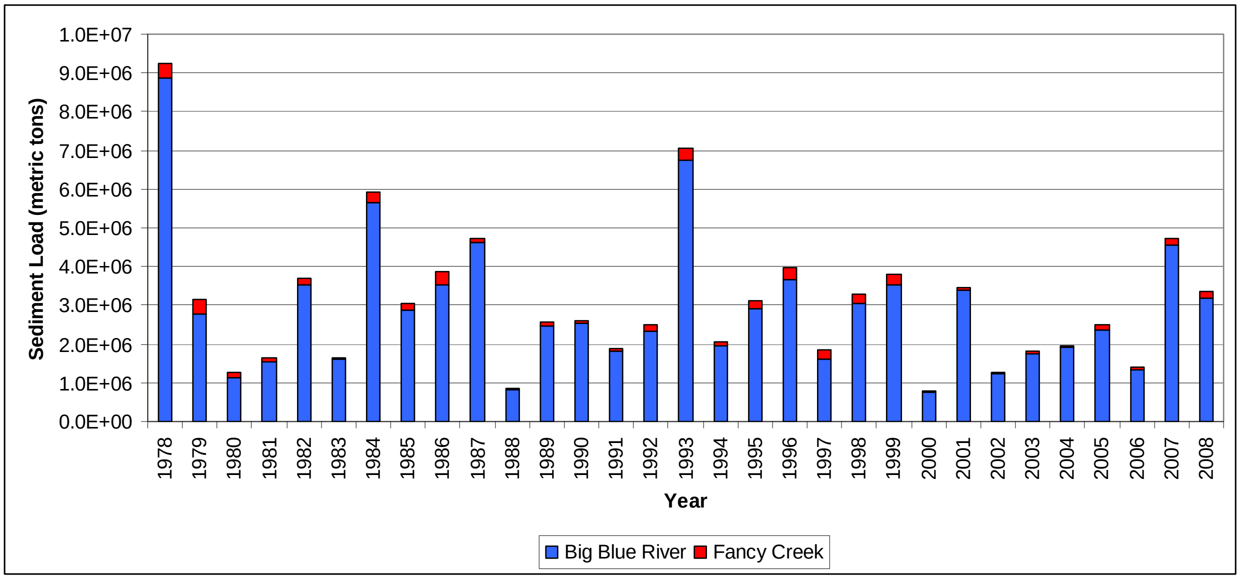


Figure 58 Annual sediment load contributions to TCL

APPENDIX B: SIMULATION CODE

Example Code for Targeted BMP Implementation focusing on sediment and $50,000 annual budget

```
%Full information BMP implementation, Marginal Gains based implementation
%Sediment Reduction

clear %clears workspace; comment this out if using MasterRunFile
clc %clears command window
delete ('BestS_15yr_50K.xls') %deletes existing Excel spreadsheet output
OutFile = 'C:\Documents and Settings\Craig Smith\My
Documents\Ph.D\Cost_Effective_WS_Management\SimModel_6\BestS_15yr_50K.xls';

warning off MATLAB:divideByZero

%What are the Sediment reduction goals and budget constraint and iterations? comment if
%using MasterRunFile
RedGoal = 100000000;
Budget = 50000;
xpercent = 0.25; %percent of farms to eliminate
iterationsbest = 3000; %number of iterations (e.g., 1000 or more)

%Load Cost and Quantity data
WSdata = xlsread('Tuttle_Model_Data.xls', 'MATinput','A2:O1859');
TotFarms = size(WSdata,1);
SubWS = WSdata(:,2);
num_counties = 10; %number of counties
num_BMPs = 3; %number of BMPs available
seed_value = 31517; %seed value

%Need to eliminate "xpercent" of the farms because we will assume that
%xpercent of the farms have already adopted BMPs or will never adopt BMPs
ineligiblefarms = round(xpercent*TotFarms);

%---------------------------------
SubWS_percent = xlsread('BMPCosts_15yrs.xls','input','D3:AH12');

%Create a matrix with max(SubWS) columns representing the subwatersheds
%and the data in the rows represents which HRUs belong to each subwatershed
SW = zeros(TotFarms,max(SubWS)); %preallocate a TotFarms by max(SubWS) matrix
for i=1:max(SubWS)
   SW_a = find(SubWS==i);
   SW_b = zeros(TotFarms - size(SW_a,1),1); %need to add a column vector of zeros to make each
vector the same length
   SW_c = cat(1,SW_a,SW_b);
   SW(:,i) = SW_c; %SW is the resulting matrix
end;
```

```
%--------------------------------------
%need a 1 by num of SubWS's matrix with number of HRUs in each SubWS
SW_count = zeros(1,max(SubWS)); %preallocate
for i = 1:max(SubWS)
   SW_count(1,i) = max(find(SW(:,i)>0)); %this is # of HRUs in each SubWS
end;

Co_SW_matrix = SubWS_percent(:,1:max(SubWS)); %this is % of SubWS in each county
Co_SW_matrix_1 = zeros(num_counties,max(SubWS)); %preallocate

for i = 1:num_counties
   Co_SW_matrix_1(i,:) = round((Co_SW_matrix(i,:).*SW_count)-.05); %subtract .05 so that we don't
get any negative #'s in
   %the Co_SW_matrix_2 which is calculated next
end;
%---------------------------------------
%Need to make sure each column adds up to the correct number of HRUs
Co_SW_matrix_2 = zeros(1,max(SubWS));

for i = 1:max(SubWS)
   Co_SW_matrix_2(1,i) = SW_count(1,i) - sum(Co_SW_matrix_1(1:9,i));
end;

Co_SW_matrix_1(num_counties,:) = Co_SW_matrix_2;
%---------------------------------------

BMP_ann_costs = SubWS_percent(:,29:31);
BMP_cost_matrix = zeros(TotFarms,num_BMPs); %preallocate a matrix with TotFarms by 3 (# of
BMPs) columns
BMP_matrix1 = zeros(TotFarms,max(SubWS));
BMP_matrix2 = zeros(TotFarms,max(SubWS));
BMP_matrix3 = zeros(TotFarms,max(SubWS));

for j = 1:max(SubWS)
   A = 0;
   for i = 1:num_counties
      if Co_SW_matrix_1(i,j) == 0
         continue
      end
      BMP_matrix1(A+1:Co_SW_matrix_1(i,j)+A,j) = BMP_ann_costs(i,1);
      BMP_matrix2(A+1:Co_SW_matrix_1(i,j)+A,j) = BMP_ann_costs(i,2);
      BMP_matrix3(A+1:Co_SW_matrix_1(i,j)+A,j) = BMP_ann_costs(i,3);
      A = Co_SW_matrix_1(i,j)+A;
   end;
end;

%---------------------------------------
%Subdivide matrix into column vectors cell arrays

for i = 1:max(SubWS)
```

```
    y{i} = zeros(TotFarms,1);%preallocate
    bmp1{i} = zeros(TotFarms,1);
    bmp2{i} = zeros(TotFarms,1);
    bmp3{i} = zeros(TotFarms,1);
end;

for i = 1:max(SubWS)
    y{i} = SW(:,i);
end

for i = 1:max(SubWS)
    bmp1{i} = BMP_matrix1(:,i);
end

for i = 1:max(SubWS)
    bmp2{i} = BMP_matrix2(:,i);
end

for i = 1:max(SubWS)
    bmp3{i} = BMP_matrix3(:,i);
end
%-----------------------------------------

%Get rid of zeros in each column vector
for i=1:max(SubWS)
    y_new{i} = y{1,i}(y{1,i}~=0);
end

for i=1:max(SubWS)
    bmp1_new{i} = bmp1{1,i}(bmp1{1,i}~=0);
end

for i=1:max(SubWS)
    bmp2_new{i} = bmp2{1,i}(bmp2{1,i}~=0);
end

for i=1:max(SubWS)
    bmp3_new{i} = bmp3{1,i}(bmp3{1,i}~=0);
end

%-----------------------------------------

%Combine common Subwatershed vectors, so the result will be 3 BMP cost
%column vectors. We can then randomly pair these using the randswap function
for i = 1:max(SubWS)
    combined_bmpcosts{i} = cat(2,bmp1_new{1,i},bmp2_new{1,i},bmp3_new{1,i});
end
rand('seed',seed_value); %set seed value

%-----------------------------------------
%Start simulating the BMP implementation scenarios. Note that this is the
```

```
%outerloop

for j = 1:iterationsbest
    j
    tic;
    HRU_id = WSdata(:,1);
    FarmArea = WSdata(:,3);
    BaseNLoad = WSdata(:,4);
    BMP1NLoad = WSdata(:,5);
    BMP2NLoad = WSdata(:,6);
    BMP3NLoad = WSdata(:,7);

    BMP1NQuantity = BaseNLoad - BMP1NLoad;
    BMP2NQuantity = BaseNLoad - BMP2NLoad;
    BMP3NQuantity = BaseNLoad - BMP3NLoad;

    BasePLoad = WSdata(:,8);
    BMP1PLoad = WSdata(:,9);
    BMP2PLoad = WSdata(:,10);
    BMP3PLoad = WSdata(:,11);

    BMP1PQuantity = BasePLoad - BMP1PLoad;
    BMP2PQuantity = BasePLoad - BMP2PLoad;
    BMP3PQuantity = BasePLoad - BMP3PLoad;

    BaseSLoad = WSdata(:,12);
    BMP1SLoad = WSdata(:,13);
    BMP2SLoad = WSdata(:,14);
    BMP3SLoad = WSdata(:,15);

    BMP1SQuantity = BaseSLoad - BMP1SLoad;
    BMP2SQuantity = BaseSLoad - BMP2SLoad;
    BMP3SQuantity = BaseSLoad - BMP3SLoad;

    %Now randomly pair the combined BMP costs matrix with an HRU
    for i = 1:max(SubWS)
        rand_bmpcosts = randswap(combined_bmpcosts{1,i});
        SW_bmpcosts{i} = cat(2,y_new{1,i},rand_bmpcosts);
    end

    %Reshape and order the bmpcosts matrix in numerical order by the first
    %column which is HRU id number
    SW_bmpcosts = reshape(SW_bmpcosts,max(SubWS),1);
    stacked_bmpcosts = cell2mat(SW_bmpcosts);
    ordered_HRU_bmpcosts = sortrows(stacked_bmpcosts,1);

    %Determine Total and Average BMP costs for each HRU for N,P, and S

    %Nitrogen Costs
    BMP1NCost = ordered_HRU_bmpcosts(:,2).*FarmArea;
    BMP2NCost = ordered_HRU_bmpcosts(:,3).*FarmArea;
```

```
    BMP3NCost = ordered_HRU_bmpcosts(:,4).*FarmArea;

    AVGBMP1NCost = BMP1NCost./BMP1NQuantity;
    AVGBMP2NCost = BMP2NCost./BMP2NQuantity;
    AVGBMP3NCost = BMP3NCost./BMP3NQuantity;

    %Phosphorus Costs
    BMP1PCost = ordered_HRU_bmpcosts(:,2).*FarmArea;
    BMP2PCost = ordered_HRU_bmpcosts(:,3).*FarmArea;
    BMP3PCost = ordered_HRU_bmpcosts(:,4).*FarmArea;

    AVGBMP1PCost = BMP1PCost./BMP1PQuantity;
    AVGBMP2PCost = BMP2PCost./BMP2PQuantity;
    AVGBMP3PCost = BMP3PCost./BMP3PQuantity;

    %Sediment Costs
    BMP1SCost = ordered_HRU_bmpcosts(:,2).*FarmArea;
    BMP2SCost = ordered_HRU_bmpcosts(:,3).*FarmArea;
    BMP3SCost = ordered_HRU_bmpcosts(:,4).*FarmArea;

    AVGBMP1SCost = BMP1SCost./BMP1SQuantity;
    AVGBMP2SCost = BMP2SCost./BMP2SQuantity;
    AVGBMP3SCost = BMP3SCost./BMP3SQuantity;

    %Get rid of zeros and negatives in Average BMP cost matricies
    BMPsAVGNCosts = cat(2,AVGBMP1NCost,AVGBMP2NCost,AVGBMP3NCost);
    findzerosN = find(BMPsAVGNCosts<=0); %finds zeros and negatives in BMPsAVGNCosts matrix
    BMPsAVGNCosts(findzerosN) = nan; %replaces zeros and negatives with nan's which is need for this program

    BMPsAVGPCosts = cat(2,AVGBMP1PCost,AVGBMP2PCost,AVGBMP3PCost);
    findzerosP = find(BMPsAVGPCosts<=0); %finds zeros and negatives in BMPsAVGPCosts matrix
    BMPsAVGPCosts(findzerosP) = nan; %replaces zeros and negatives with nan's which is need for this program

    BMPsAVGSCosts = cat(2,AVGBMP1SCost,AVGBMP2SCost,AVGBMP3SCost);
    findzerosS = find(BMPsAVGSCosts<=0); %finds zeros and negatives in BMPsAVGSCosts matrix
    BMPsAVGSCosts(findzerosS) = nan; %replaces zeros and negatives with nan's which is need for this program

    %Get rid of the negatives and zeros
    NReductions = cat(2, BMP1NQuantity, BMP2NQuantity, BMP3NQuantity);
    PReductions = cat(2, BMP1PQuantity, BMP2PQuantity, BMP3PQuantity);
    SReductions = cat(2, BMP1SQuantity, BMP2SQuantity, BMP3SQuantity);

    % findreductionsN = find(NReductions<0); %finds negative values in N reductions data
    % NReductions(findreductionsN) = 0; %replaces negatives with zeros

    % findreductionsP = find(PReductions<0); %finds negative values in P reductions data
    % PReductions(findreductionsP) = 0; %replaces negatives with zeros
```

```
findreductionsS = find(SReductions<0); %finds negative values in S reductions data
SReductions(findreductionsS) = 0; %replaces negatives with zeros

%Need to eliminate "xpercent" of the farms because we will assume that
%xpercent of the farms have already adopted BMPs or will never adopt
%BMPs. This is done by randomly selecting xpercent of the farms and
%setting the appropriate rows in the BMPsAVGSCosts to zero. Note that
%if we were trading in regards to another pollutant (N or P), then this
%code would need to be changed to the appropriate BMP Avg Cost matrix.
%If there are already more farms with negatives and zeros than
%ineligible farms, then this piece of code has no effect

num_of_zeros = size(find(SReductions(:,1) == 0),1);
while num_of_zeros < ineligiblefarms
   eliminate_id = round(rand(1)*TotFarms);
   if eliminate_id == 0
      continue
   end
   SReductions(eliminate_id,1:3) = zeros(1,3);
   num_of_zeros = size(find(SReductions(:,1) == 0),1);
end;
num_of_zeros = size(find(SReductions(:,1) == 0),1);

findreductionsS_zeros = find(SReductions == 0);
BMPsAVGSCosts(findreductionsS_zeros) = nan;%set corresponding cells in BMPAVG S Cost
%matrix to nan

CummNQuantity = 0;
TotBMPNCost1 = 0;
CummPQuantity = 0;
TotBMPPCost1 = 0;
CummSQuantity = 0;
TotBMPSCost1 = 0;
zeromatrix = zeros(TotFarms,num_BMPs);%zeros matrix of dimension TotFarms x 3 which is # of
BMPs
nanmatrix = nan(TotFarms,num_BMPs);%nan matrix of dimension TotFarms x 3 which is # of BMPs

%This is the innerloop where the actual BMP implementation occurs
i = 0;
while (CummSQuantity < RedGoal) && (i < TotFarms) %loop while below reduction goal AND while
the number of
   %BMP projects implemented is less than or equal to the total number of farms (this is because each
   %farm can only implement one BMP)

   [FarmID,BMP] = find(min(min(BMPsAVGSCosts)) == BMPsAVGSCosts); %Find minimum avg
PCost

   if BMPsAVGSCosts(FarmID,BMP) == nan %if there is zero SCost for BMP implementation
      %set that Farm-BMP Combo to nan and the corresponding SReductions value to zero
      BMPsAVGSCosts(FarmID,BMP) = nan;
      SReductions(FarmID,BMP) = 0;
```

```
            continue; %go back to the start of the while loop
        end;

        if SReductions == zeromatrix
            break; end;

%       if BMPsAVGSCosts == nanmatrix %this can be commented out if the
%       budget and/or reduction goal are binding
%           break; end;

        if size ([FarmID,BMP],1) > 1  %If there are BMPs (and/or Farms) with identical SCosts, pick the
first one
            FarmID = FarmID(1);
            BMP = BMP(1);
        end;

        AVGPracticeSCost = BMPsAVGSCosts(FarmID,BMP);
        Area = FarmArea(FarmID,1);
        NQuantity = NReductions(FarmID,BMP);
        PQuantity = PReductions(FarmID,BMP);
        SQuantity = SReductions(FarmID,BMP);
        TotPracticeSCost = AVGPracticeSCost*SQuantity;

        if (TotPracticeSCost + TotBMPSCost1) > Budget
            BMPsAVGSCosts(FarmID,BMP) = nan;
            SReductions(FarmID,BMP) = 0;
            continue;
        end; %if implementing this BMP will exceed the budget, take that Farm-BMP Combo out of the
market

        SReductions(FarmID,BMP) = SReductions(FarmID,BMP) - SQuantity; %Update SReductions1
Matrix
        i = i + 1;

        if SReductions(FarmID,BMP) == 0
            BMPsAVGSCosts(FarmID,:) = nan; %If the previous BMP was fully implemented, take that farm
out of the market
            SReductions(FarmID,:) = 0;
        end;

        if i == 1 %save data
            Simout = [Area, FarmID, BMP, AVGPracticeSCost, SQuantity, TotPracticeSCost];
            OtherSimout = [NQuantity, PQuantity];
        else Simout = [Simout; Area, FarmID, BMP, AVGPracticeSCost, SQuantity, TotPracticeSCost];
            OtherSimout = [OtherSimout; NQuantity, PQuantity];
        end;

        Count = (1:i)'; %this numbers the rows in the first column of output
        TotArea = sum(Simout(:,1));
        CummSQuantity = sum(Simout(:,5));
        TotBMPSCost = sum(Simout(:,6));
```

```
        TotBMPSCost1 = TotBMPSCost + 0;
        CummNQuantity = sum(OtherSimout(:,1));
        CummPQuantity = sum(OtherSimout(:,2));
        numofBMP1 = size(find(Simout(:,3)==1),1); %calculates # of BMP1 implemented
        numofBMP2 = size(find(Simout(:,3)==2),1); %calculates # of BMP2 implemented
        numofBMP3 = size(find(Simout(:,3)==3),1); %calculates # of BMP3 implemented
    end;

    a = nan(i-1,1); %nan matrix that is i-1 rows and 1 column
    TotBMPnumOUT = cat(1,i,a); %the scalar value is inserted at top of a matrix to make
    %a i x 1 matrix for output purposes - same procedure for next 5
    %output variables
    TotAreaOUT = cat(1,TotArea,a);
    TotBMPSCostOUT = cat(1,TotBMPSCost,a);
    RedGoalOUT = cat(1,RedGoal,a);
    BudgetOUT = cat(1,Budget,a);
    CummNQuantityOUT = cat(1,CummNQuantity,a);
    CummPQuantityOUT = cat(1,CummPQuantity,a);
    CummSQuantityOUT = cat(1,CummSQuantity,a);
    numofBMP1OUT = cat(1,numofBMP1,a);
    numofBMP2OUT = cat(1,numofBMP2,a);
    numofBMP3OUT = cat(1,numofBMP3,a);

    Output = cat(2,Count, Simout, OtherSimout, TotBMPnumOUT, TotAreaOUT, CummSQuantityOUT,
TotBMPSCostOUT, RedGoalOUT,...
        BudgetOUT, CummNQuantityOUT, CummPQuantityOUT, numofBMP1OUT, numofBMP2OUT,
numofBMP3OUT);
    %     numericalOutput = num2cell(Output); %change the numerical array into a cell array

    OUT{j} = {Output};
    toc
    time2{j} = toc;
end;

disp ('Successfully finished the iterations!!')
%------------------------------------------------

%Finds the maximum number of BMP projects implemented(rows) in the output data. Changes all
%matrices to have the same number of rows. Zeros are put in the rows that
%are added.For more information, go to section 15.3 in the array manipulation
%publication


for j=1:iterationsbest
    b(j) = max(OUT{1,j}{1,1}(:,1)); %finds total # of BMP projects implemented in each iteration
end;

m = mean(b); %finds average # of BMP projects implemented across all iterations
m = round(m); %rounds the average # to nearest whole number
% aa = a(:)'; %creates another matrix aa equal to a
% aa = aa(ones(m,1),:); %transforms aa into an m by iterations matrix
```

```
bb = (1:m)'; %creates bb which is a column vector going from 1 to m
% bb = bb(:,ones(length(a), 1)); %transforms bb into a m by iterations matrix
% %with each column going from 1 to m
% b = bb .* (bb <= aa); %the dot indicates array multiplication (not the same
% %as matrix multiplication. Arrays in bb are multiplied by an array of ones
% %and zeros corresponding to the number of BMP projects implemented
% M = mean(b,2); %sums across all rows of the b matrix resulting in a column vector

for i = 1:iterationsbest %this loop equalizes number of rows (equal to mean # of BMP projects
implemented)
    %across all iterations so that the means can be calcualted
    cc{i} = OUT{i}{1}(:,2); %area
    ee{i} = OUT{i}{1}(:,6); %tons of soil reduction
    ff{i} = OUT{i}{1}(:,7); %total BMP cost
    gg{i} = OUT{i}{1}(:,8); %pounds of N reduction
    hh{i} = OUT{i}{1}(:,9); %pounds of P reduction
    ii{i} = OUT{i}{1}(1,10); %num of BMPs
    jj{i} = OUT{i}{1}(1,11); %total area
    kk{i} = OUT{i}{1}(1,12); %cummulative soil reduction
    ll{i} = OUT{i}{1}(1,13); %total BMP costs
    mm{i} = OUT{i}{1}(1,14); %soil reduction goal
    nn{i} = OUT{i}{1}(1,15); %budget
    oo{i} = OUT{i}{1}(1,16); %cummulative N reduction
    pp{i} = OUT{i}{1}(1,17); %cummulative P reduction
    qq{i} = OUT{i}{1}(1,18); %num of BMP1 implemented
    rr{i} = OUT{i}{1}(1,19); %num of BMP2 implemented
    ss{i} = OUT{i}{1}(1,20); %num of BMP3 implemented

    [u,y] = size(cc{i});
    if u >= m
        cc1{i} = cc{i}(1:m,:);
        ee1{i} = ee{i}(1:m,:);
        ff1{i} = ff{i}(1:m,:);
        gg1{i} = gg{i}(1:m,:);
        hh1{i} = hh{i}(1:m,:);
    else v = m-u;
        w = zeros(v,1);
        cc1{i} = cat(1,cc{i},w);
        ee1{i} = cat(1,ee{i},w);
        ff1{i} = cat(1,ff{i},w);
        gg1{i} = cat(1,gg{i},w);
        hh1{i} = cat(1,hh{i},w);
    end;
end;

%convert cell array of matricies to single matrix
ccc = cell2mat(cc1);
eee = cell2mat(ee1);
fff = cell2mat(ff1);
ggg = cell2mat(gg1);
hhh = cell2mat(hh1);
```

```
iii = cell2mat(ii);
jjj = cell2mat(jj);
kkk = cell2mat(kk);
lll = cell2mat(ll);
mmm = cell2mat(mm);
nnn = cell2mat(nn);
ooo = cell2mat(oo);
ppp = cell2mat(pp);
qqq = cell2mat(qq);
rrr = cell2mat(rr);
sss = cell2mat(ss);
ddd = sum(mean(fff,2))/sum(mean(eee,2)); %avg S reduction costs (total)
ttt = sum(mean(fff,2))/sum(mean(ggg,2)); %avg N reduction costs (total)
uuu = sum(mean(fff,2))/sum(mean(hhh,2)); %avg P reduction costs (total)

%finds mean of rows
mccc = mean(ccc,2); %area
meee = mean(eee,2); %tons of soil reduction
mfff = mean(fff,2); %total BMP cost
mvvv = mfff./meee; %avg S reduction incremental costs
mddd = cat(1,mean(ddd,2),nan(m-1,1)); %avg S reduction costs (total)
mggg = mean(ggg,2); %pounds of N reduction
mwww = mfff./mggg; %avg N reduction incremental costs
mttt = cat(1,mean(ttt,2),nan(m-1,1)); %avg N reduction costs (total)
mhhh = mean(hhh,2); %pounds of P reduction
mxxx = mfff./mhhh; %avg P reduction incremental costs
muuu = cat(1,mean(uuu,2),nan(m-1,1)); %avg P reduction costs (total)
miii = cat(1,mean(iii,2),nan(m-1,1)); %num of BMPs
mjjj = cat(1,sum(mccc),nan(m-1,1)); %total area
mkkk = cat(1,sum(meee),nan(m-1,1)); %cummulative soil reduction
mlll = cat(1,sum(mfff),nan(m-1,1)); %total BMP costs
mmmm = cat(1,mean(mmm,2),nan(m-1,1)); %soil reduction goal
mnnn = cat(1,mean(nnn,2),nan(m-1,1)); %budget
mooo = cat(1,sum(mggg),nan(m-1,1)); %cummulative N reduction
mppp = cat(1,sum(mhhh),nan(m-1,1)); %cummulative P reduction
mqqq = cat(1,mean(qqq,2),nan(m-1,1)); %num of BMP1 implemented
mrrr = cat(1,mean(rrr,2),nan(m-1,1)); %num of BMP2 implemented
msss = cat(1,mean(sss,2),nan(m-1,1)); %num of BMP3 implemented

SumOut =
cat(2,bb,mccc,mfff,meee,mvvv,mddd,mggg,mwww,mttt,mhhh,mxxx,muuu,miii,mjjj,mlll,mmmm,mnnn,
mkkk,mooo,mppp,mqqq,mrrr,msss);
SumOutcell = num2cell(SumOut);
Headings = {'#' 'Area (ac)' 'TotBMPCost' 'S_Quantity (tons)' 'AVGincremCost_S (/ton)' 'AVGred_S_Cost
(/ton)' 'N_Quantity (lbs)' 'AVGincremCost_N (/lb)'...
    'AVGred_N_Cost (/lb)' 'P_Quantity (lbs)' 'AVGincremCost_P (/lb)' 'AVGred_P_Cost (/lb)'
'TotBMPnum' 'Total Area (ac)' 'TotBMPCost'...
    'S_RedGoal (tons)' 'Budget' 'Cumm_S_Quantity (tons)' 'Cumm_N_Quantity (lbs)' 'Cumm_P_Quantity
(lbs)'...
    '# of BMP1' '# of BMP2' '#of BMP3'};
```

```
allOutput = [Headings; SumOutcell];
xlswrite('BestS_15yr_50K.xls',allOutput,1,'A1');

%----------------------------------------------------------------

% Run OfficeDoc to format Excel output
% Open document in 'append' mode:
[file,status,errMsg] = officedoc('BestS_15yr_50K.xls', 'open', 'mode','append');

status = officedoc(file, 'format', 'sheet', 1, 'Range', 'A1:W1', 'bold','on','WrapText',1);
status = officedoc(file, 'format', 'sheet', 1, 'Range', 'D:D,E:E,F2,H:H,I2,K:K,L2',
'NumberFormat','$#,##0.00');
status = officedoc(file, 'format', 'sheet', 1, 'Range', 'D:D,G:G,J:J,U2,V2,W2', 'NumberFormat','#,##0.00');
status = officedoc(file, 'format', 'sheet', 1, 'Range', 'C:C,O2,Q2', 'NumberFormat','$#,##0');
status = officedoc(file, 'format', 'sheet', 1, 'Range', 'B:B, M2,N2,P2,R2,S2,T2', 'NumberFormat','#,##0');
status = officedoc(file, 'format', 'sheet', 1, 'Range', 'A:W', 'ColAutoFit',1);

% Close the document, deleting standard sheets and releasing COM server:
status = officedoc(file, 'close', 'release',1,'delStd','off');
toc
% Re-display document; file is no longer valid so we must use file name:
%officedoc('BestS_15yr_50K.xls', 'display');
```

Example Code for Random BMP Implementation focusing on sediment and $50,000 annual budget

```
%Random BMP implementation
%Sediment Reduction

clear %clears workspace; comment this out if using MasterRunFile
clc %clears command window
delete ('RandS_15yr_50K.xls') %deletes existing Excel spreadsheet output
OutFile = 'C:\Documents and Settings\Craig Smith\My
Documents\Ph.D\Cost_Effective_WS_Management\SimModel_6\RandS_15yr_50K.xls';

warning off MATLAB:divideByZero

%What are the Sediment reduction goals and budget constraint and iterations? comment if
%using MasterRunFile
RedGoal = 100000000;
Budget = 50000;
xpercent = .25; %percent of farms to eliminate
iterations = 3150; %number of iterations (e.g., 1000 or more ** note: increase by roughly 5%)

%Load Cost and Quantity data
WSdata = xlsread('Tuttle_Model_Data.xls', 'MATinput','A2:O1859');
TotFarms = size(WSdata,1);
SubWS = WSdata(:,2);
num_counties = 10; %number of counties
num_BMPs = 3; %number of BMPs available
seed_value = 31517; %seed value

%Need to eliminate "xpercent" of the farms because we will assume that
%xpercent of the farms have already adopted BMPs or will never adopt BMPs
ineligiblefarms = round(xpercent*TotFarms);

%---------------------------------
SubWS_percent = xlsread('BMPCosts_15yrs.xls','input','D3:AH12');

%Create a matrix with max(SubWS) columns representing the subwatersheds
%and the data in the rows represents which HRUs belong to each subwatershed
SW = zeros(TotFarms,max(SubWS)); %preallocate a TotFarms by max(SubWS) matrix
for i=1:max(SubWS)
   SW_a = find(SubWS==i);
   SW_b = zeros(TotFarms - size(SW_a,1),1); %need to add a column vector of zeros to make each
vector the same length
   SW_c = cat(1,SW_a,SW_b);
   SW(:,i) = SW_c; %SW is the resulting matrix
end;

%-------------------------------------
```

```
%need a 1 by num of SubWS's matrix with number of HRUs in each SubWS
SW_count = zeros(1,max(SubWS)); %preallocate
for i = 1:max(SubWS)
   SW_count(1,i) = max(find(SW(:,i)>0)); %this is # of HRUs in each SubWS
end;

Co_SW_matrix = SubWS_percent(:,1:max(SubWS)); %this is % of SubWS in each county
Co_SW_matrix_1 = zeros(num_counties,max(SubWS)); %preallocate

for i = 1:num_counties
   Co_SW_matrix_1(i,:) = round((Co_SW_matrix(i,:).*SW_count)-.05); %subtract .05 so that we don't
get any negative #'s in
   %the Co_SW_matrix_2 which is calculated next
end;
%----------------------------------------
%Need to make sure each column adds up to the correct number of HRUs
Co_SW_matrix_2 = zeros(1,max(SubWS));

for i = 1:max(SubWS)
   Co_SW_matrix_2(1,i) = SW_count(1,i) - sum(Co_SW_matrix_1(1:9,i));
end;

Co_SW_matrix_1(num_counties,:) = Co_SW_matrix_2;
%----------------------------------------

BMP_ann_costs = SubWS_percent(:,29:31);
BMP_cost_matrix = zeros(TotFarms,num_BMPs); %preallocate a matrix with TotFarms by 3 (# of
BMPs) columns
BMP_matrix1 = zeros(TotFarms,max(SubWS));
BMP_matrix2 = zeros(TotFarms,max(SubWS));
BMP_matrix3 = zeros(TotFarms,max(SubWS));

for j = 1:max(SubWS)
   A = 0;
   for i = 1:num_counties
      if Co_SW_matrix_1(i,j) == 0
         continue
      end
      BMP_matrix1(A+1:Co_SW_matrix_1(i,j)+A,j) = BMP_ann_costs(i,1);
      BMP_matrix2(A+1:Co_SW_matrix_1(i,j)+A,j) = BMP_ann_costs(i,2);
      BMP_matrix3(A+1:Co_SW_matrix_1(i,j)+A,j) = BMP_ann_costs(i,3);
      A = Co_SW_matrix_1(i,j)+A;
   end;
end;

%----------------------------------------
%Subdivide matrix into column vectors cell arrays

for i = 1:max(SubWS)
   y{i} = zeros(TotFarms,1);%preallocate
   bmp1{i} = zeros(TotFarms,1);
```

```
    bmp2{i} = zeros(TotFarms,1);
    bmp3{i} = zeros(TotFarms,1);
end;

for i = 1:max(SubWS)
    y{i} = SW(:,i);
end

for i = 1:max(SubWS)
    bmp1{i} = BMP_matrix1(:,i);
end

for i = 1:max(SubWS)
    bmp2{i} = BMP_matrix2(:,i);
end

for i = 1:max(SubWS)
    bmp3{i} = BMP_matrix3(:,i);
end
%----------------------------------------

%Get rid of zeros in each column vector
for i=1:max(SubWS)
    y_new{i} = y{1,i}(y{1,i}~=0);
end

for i=1:max(SubWS)
    bmp1_new{i} = bmp1{1,i}(bmp1{1,i}~=0);
end

for i=1:max(SubWS)
    bmp2_new{i} = bmp2{1,i}(bmp2{1,i}~=0);
end

for i=1:max(SubWS)
    bmp3_new{i} = bmp3{1,i}(bmp3{1,i}~=0);
end

%---------------------------------------

%Combine common Subwatershed vectors, so the result will be 3 BMP cost
%column vectors. We can then randomly pair these using the randswap function
for i = 1:max(SubWS)
    combined_bmpcosts{i} = cat(2,bmp1_new{1,i},bmp2_new{1,i},bmp3_new{1,i});
end

%----------------------------------------
%Outer loop for testing purposes
% for k=1:1
%keep3 function is a complement to the clear fcn. in that it clears all
%variables except the ones listed
```

```
keep3 combined_bmpcosts RedGoal Budget xpercent iterations WSdata TotFarms SubWS num_counties
num_BMPs ineligiblefarms OutFile y_new seed_value
rand('seed',seed_value);%set seed value
OUT = cell(1,iterations);
%----------------------------------------
%Start simulating the BMP implementation scenarios. Note that this is the
%outerloop
for j = 1:iterations
   j
   tic;
   HRU_id = WSdata(:,1);
   FarmArea = WSdata(:,3);
   BaseNLoad = WSdata(:,4);
   BMP1NLoad = WSdata(:,5);
   BMP2NLoad = WSdata(:,6);
   BMP3NLoad = WSdata(:,7);

   BMP1NQuantity = BaseNLoad - BMP1NLoad;
   BMP2NQuantity = BaseNLoad - BMP2NLoad;
   BMP3NQuantity = BaseNLoad - BMP3NLoad;

   BasePLoad = WSdata(:,8);
   BMP1PLoad = WSdata(:,9);
   BMP2PLoad = WSdata(:,10);
   BMP3PLoad = WSdata(:,11);

   BMP1PQuantity = BasePLoad - BMP1PLoad;
   BMP2PQuantity = BasePLoad - BMP2PLoad;
   BMP3PQuantity = BasePLoad - BMP3PLoad;

   BaseSLoad = WSdata(:,12);
   BMP1SLoad = WSdata(:,13);
   BMP2SLoad = WSdata(:,14);
   BMP3SLoad = WSdata(:,15);

   BMP1SQuantity = BaseSLoad - BMP1SLoad;
   BMP2SQuantity = BaseSLoad - BMP2SLoad;
   BMP3SQuantity = BaseSLoad - BMP3SLoad;

   %Now randomly pair the combined BMP costs matrix with an HRU
   for i = 1:max(SubWS)
      rand_bmpcosts = randswap(combined_bmpcosts{1,i});
      SW_bmpcosts{i} = cat(2,y_new{1,i},rand_bmpcosts);
   end

   %Reshape and order the bmpcosts matrix in numerical order by the first
   %column which is HRU id number
   SW_bmpcosts = reshape(SW_bmpcosts,max(SubWS),1);
   stacked_bmpcosts = cell2mat(SW_bmpcosts);
   ordered_HRU_bmpcosts = sortrows(stacked_bmpcosts,1);
```

```
%Determine Total and Average BMP costs for each HRU for N,P, and S

%Nitrogen Costs
BMP1NCost = ordered_HRU_bmpcosts(:,2).*FarmArea;
BMP2NCost = ordered_HRU_bmpcosts(:,3).*FarmArea;
BMP3NCost = ordered_HRU_bmpcosts(:,4).*FarmArea;

AVGBMP1NCost = BMP1NCost./BMP1NQuantity;
AVGBMP2NCost = BMP2NCost./BMP2NQuantity;
AVGBMP3NCost = BMP3NCost./BMP3NQuantity;

AVGBMP1NCost(isinf(AVGBMP1NCost)) = 0; %replace infinity values with zeros
AVGBMP2NCost(isinf(AVGBMP2NCost)) = 0; %replace infinity values with zeros
AVGBMP3NCost(isinf(AVGBMP3NCost)) = 0; %replace infinity values with zeros

%Phosphorus Costs
BMP1PCost = ordered_HRU_bmpcosts(:,2).*FarmArea;
BMP2PCost = ordered_HRU_bmpcosts(:,3).*FarmArea;
BMP3PCost = ordered_HRU_bmpcosts(:,4).*FarmArea;

AVGBMP1PCost = BMP1PCost./BMP1PQuantity;
AVGBMP2PCost = BMP2PCost./BMP2PQuantity;
AVGBMP3PCost = BMP3PCost./BMP3PQuantity;

AVGBMP1PCost(isinf(AVGBMP1PCost)) = 0; %replace infinity values with zeros
AVGBMP2PCost(isinf(AVGBMP2PCost)) = 0; %replace infinity values with zeros
AVGBMP3PCost(isinf(AVGBMP3PCost)) = 0; %replace infinity values with zeros

%Sediment Costs
BMP1SCost = ordered_HRU_bmpcosts(:,2).*FarmArea;
BMP2SCost = ordered_HRU_bmpcosts(:,3).*FarmArea;
BMP3SCost = ordered_HRU_bmpcosts(:,4).*FarmArea;

AVGBMP1SCost = BMP1SCost./BMP1SQuantity;
AVGBMP2SCost = BMP2SCost./BMP2SQuantity;
AVGBMP3SCost = BMP3SCost./BMP3SQuantity;

AVGBMP1SCost(isinf(AVGBMP1SCost)) = 0; %replace infinity values with zeros
AVGBMP2SCost(isinf(AVGBMP2SCost)) = 0; %replace infinity values with zeros
AVGBMP3SCost(isinf(AVGBMP3SCost)) = 0; %replace infinity values with zeros

%Get rid of zeros and negatives in Average BMP cost matricies
BMPsAVGNCosts = cat(2,AVGBMP1NCost,AVGBMP2NCost,AVGBMP3NCost);
findzerosN = find(BMPsAVGNCosts<=0); %finds zeros and negatives in BMPsAVGNCosts matrix
BMPsAVGNCosts(findzerosN) = 0; %replaces zeros and negatives with 0's which is need for this
program

BMPsAVGPCosts = cat(2,AVGBMP1PCost,AVGBMP2PCost,AVGBMP3PCost);
findzerosP = find(BMPsAVGPCosts<=0); %finds zeros and negatives in BMPsAVGPCosts matrix
BMPsAVGPCosts(findzerosP) = 0; %replaces zeros and negatives with 0's which is need for this
program
```

```
BMPsAVGSCosts = cat(2,AVGBMP1SCost,AVGBMP2SCost,AVGBMP3SCost);
findzerosS = find(BMPsAVGSCosts<=0); %finds zeros and negatives in BMPsAVGSCosts matrix
BMPsAVGSCosts(findzerosS) = 0; %replaces zeros and negatives with 0's which is need for this
program

%Need to eliminate "xpercent" of the farms because we will assume that
%xpercent of the farms have already adopted BMPs or will never adopt
%BMPs. This is done by randomly selecting xpercent of the farms and
%setting the appropriate rows in the BMPsAVGSCosts to zero. Note that
%if we were addressing another pollutant (N or P), then this
%code would need to be changed to the appropriate BMP Avg Cost matrix.
%If there are already more farms with negatives and zeros than
%ineligible farms, then this piece of code has no effect

num_of_zeros = size(find(BMPsAVGSCosts(:,1) == 0),1);
while num_of_zeros < ineligiblefarms
   eliminate_id = round(rand(1)*TotFarms);
   if eliminate_id == 0
      continue
   end
   BMPsAVGSCosts(eliminate_id,1:3) = zeros(1,3);
   num_of_zeros = size(find(BMPsAVGSCosts(:,1) == 0),1);
end;
num_of_zeros = size(find(BMPsAVGSCosts(:,1) == 0),1);

%Get rid of the negatives and zeros
NReductions = cat(2, BMP1NQuantity, BMP2NQuantity, BMP3NQuantity);
PReductions = cat(2, BMP1PQuantity, BMP2PQuantity, BMP3PQuantity);
SReductions = cat(2, BMP1SQuantity, BMP2SQuantity, BMP3SQuantity);

% findreductionsN = find(NReductions<0); %finds negative values in N reductions data
% NReductions(findreductionsN) = 0; %replaces negatives with zeros

% findreductionsP = find(PReductions<0); %finds negative values in P reductions data
% PReductions(findreductionsP) = 0; %replaces negatives with zeros

findreductionsS = find(SReductions<0); %finds negative values in S reductions data
SReductions(findreductionsS) = 0; %replaces negatives with zeros

CummNQuantity = 0;
TotBMPNCost1 = 0;
CummPQuantity = 0;
TotBMPPCost1 = 0;
CummSQuantity = 0;
TotBMPSCost1 = 0;
zeromatrix = zeros(TotFarms,num_BMPs);%zeros matrix of dimension TotFarms x 3 which is # of
BMPs

%This is the innerloop where the actual BMP implementation occurs
i = 1;
```

```
   S = [1:TotFarms.*num_BMPs]';
   findzerocosts = find(BMPsAVGSCosts == 0);
   S([findzerocosts]) = [0]; % Replace some of the elements of S with zero if they have already been ruled
ineligble
   S_rand = S(randperm(size(S,1)),:); %randomize the S matrix

   %This piece of code moves all zeros to the bottom of the column vector
   S_randsort=[];
   [m,n]=size(S_rand);
   for col=1:n,
      a=zeros(m,1);
      a(1:sum(S_rand(:,col)>0))=S_rand(find(S_rand(:,col)>0),col);
      S_randsort=[S_randsort a];
   end

   mat_size = [TotFarms,num_BMPs];
   [FarmID_1,BMP_1] = ind2sub(mat_size,S_randsort); %The ind2sub command determines the
equivalent subscript values corresponding
   %to a single index into an array

   %need to eliminate duplicates from FarmID_1 and the
   %corresponding elements in BMP_1 vector. This is because only one
   %BMP can be implemented on a farm
   [FarmID_2,BMP_position] = unique_no_sort(FarmID_1); %this is a specially made function which is
similar to "unique"
   %function except that it does not sort
   FarmID_2 = (FarmID_2(1:length(FarmID_2)-1))';
   BMP_position = (BMP_position(1:length(BMP_position)-1))';

   %This loop creates the corresponding BMP_2 matrix to match the FARMID_2
   %vector created earlier
   for i = 1:length(BMP_position)
      BMP_2(i,1) = BMP_1(BMP_position(i,1),1);
   end;

   i=0;
   while (CummSQuantity < RedGoal) && (sum(sum(single(SReductions)))>0) %loop while below
reduction goal AND
      %while there are still BMPs available
      i = i+1;

      if i > length(BMP_position)
         break; end;

      FarmID = FarmID_2(i);
      BMP = BMP_2(i);

      if FarmID == 0
         break; end;

      if BMPsAVGSCosts(FarmID,BMP)>0 && SReductions(FarmID,BMP)>0
```

```
        AVGPracticeSCost = BMPsAVGSCosts(FarmID,BMP);
        Area = FarmArea(FarmID,1);
        NQuantity = NReductions(FarmID,BMP);
        PQuantity = PReductions(FarmID,BMP);
        SQuantity = SReductions(FarmID,BMP);
        TotPracticeSCost = AVGPracticeSCost*SQuantity;
      else
        continue;
      end;

      if (TotPracticeSCost + TotBMPSCost1) > Budget
        continue;
      end;

      %SReductions(FarmID,BMP) = SReductions(FarmID,BMP) - SQuantity; %Update Reductions
Matrix
      SReductions(FarmID,:) = zeros(1,num_BMPs); %after a BMP is implemented, zero out the row so
that farm is eliminated
      %from further consideration

      if i == 1 %save data
        Simout = [Area, FarmID, BMP, AVGPracticeSCost, SQuantity, TotPracticeSCost];
        OtherSimout = [NQuantity, PQuantity];
      else Simout = [Simout; Area, FarmID, BMP, AVGPracticeSCost, SQuantity, TotPracticeSCost];
        OtherSimout = [OtherSimout; NQuantity, PQuantity];
      end;

      TotArea = sum(Simout(:,1));
      CummSQuantity = sum(Simout(:,5));
      TotBMPSCost = sum(Simout(:,6));
      TotBMPSCost1 = TotBMPSCost + 0;
      CummNQuantity = sum(OtherSimout(:,1));
      CummPQuantity = sum(OtherSimout(:,2));
      numofBMP1 = size(find(Simout(:,3)==1),1); %calculates # of BMP1 implemented
      numofBMP2 = size(find(Simout(:,3)==2),1); %calculates # of BMP2 implemented
      numofBMP3 = size(find(Simout(:,3)==3),1); %calculates # of BMP3 implemented
    end;

    num_of_BMPs = size(Simout,1);
    Count = (1:num_of_BMPs)'; %this numbers the rows in the first column of output
    a = nan(num_of_BMPs-1,1); %nan matrix that is # of BMPs rows and 1 column
    TotBMPnumOUT = cat(1,num_of_BMPs,a); %the scalar value is inserted at top of a matrix to make
    %a # of BMPs x 1 matrix for output purposes - same procedure for next 5
    %output variables
    TotAreaOUT = cat(1,TotArea,a);
    TotBMPSCostOUT = cat(1,TotBMPSCost,a);
    RedGoalOUT = cat(1,RedGoal,a);
    BudgetOUT = cat(1,Budget,a);
    CummNQuantityOUT = cat(1,CummNQuantity,a);
    CummPQuantityOUT = cat(1,CummPQuantity,a);
    CummSQuantityOUT = cat(1,CummSQuantity,a);
```

```
    numofBMP1OUT = cat(1,numofBMP1,a);
    numofBMP2OUT = cat(1,numofBMP2,a);
    numofBMP3OUT = cat(1,numofBMP3,a);

    Output = cat(2,Count, Simout, OtherSimout, TotBMPnumOUT, TotAreaOUT, CummSQuantityOUT,
TotBMPSCostOUT, RedGoalOUT,...
        BudgetOUT, CummNQuantityOUT, CummPQuantityOUT, numofBMP1OUT, numofBMP2OUT,
numofBMP3OUT);
    %     numericalOutput = num2cell(Output); %change the numerical array into a cell array

    OUT{j} = {Output};
    toc
    time2{j} = toc;
end;

disp ('Successfully finished the iterations!!')
%-------------------------------------------------

%The rest of the code is for organizing and summarizing all of the output and
%reporting it in a neat formatted fashion

%Delete the cases where the budget constraint was exceeded (this somehow
%occurs in approximately 4% of the cases). So, increase the number of
%iterations by 4%. i.e., if you want 1000 good simulations, run 1040

for j=1:iterations
    costs(j,1) = OUT{1,j}{1,1}(1,13); %finds the TotBMPCost for each iteration
end;

delete_bad = find(costs > Budget)
size_delete = length(delete_bad)

for j=delete_bad
    OUT(j) = [];
end;

%Finds the maximum number of BMP projects implemented(rows) in the output data. Changes all
%matrices to have the same number of rows. Zeros are put in the rows that
%are added.For more information, go to section 15.3 in the array manipulation
%publication

iterations = iterations - size_delete;

for j=1:iterations
    b(j) = max(OUT{1,j}{1,1}(:,1)); %finds total # of BMP projects implemented in each iteration
end;

m = mean(b); %finds average # of BMP projects implemented across all iterations
m = round(m); %rounds the average # to nearest whole number
% aa = a(:)'; %creates another matrix aa equal to a
% aa = aa(ones(m,1),:); %transforms aa into an m by iterations matrix
```

```
bb = (1:m)'; %creates bb which is a column vector going from 1 to m
% bb = bb(:,ones(length(a), 1)); %transforms bb into a m by iterations matrix
% %with each column going from 1 to m
% b = bb .* (bb <= aa); %the dot indicates array multiplication (not the same
% %as matrix multiplication. Arrays in bb are multiplied by an array of ones
% %and zeros corresponding to the number of BMP projects implemented
% M = mean(b,2); %sums across all rows of the b matrix resulting in a column vector

for i = 1:iterations %this loop equalizes number of rows (equal to mean # of BMP projects implemented)
    %across all iterations so that the means can be calcualted
    cc{i} = OUT{i}{1}(:,2); %area
    ee{i} = OUT{i}{1}(:,6); %tons of soil reduction
    ff{i} = OUT{i}{1}(:,7); %total BMP cost
    gg{i} = OUT{i}{1}(:,8); %pounds of N reduction
    hh{i} = OUT{i}{1}(:,9); %pounds of P reduction
    ii{i} = OUT{i}{1}(1,10); %num of BMPs
    jj{i} = OUT{i}{1}(1,11); %total area
    kk{i} = OUT{i}{1}(1,12); %cummulative soil reduction
    ll{i} = OUT{i}{1}(1,13); %total BMP costs
    mm{i} = OUT{i}{1}(1,14); %soil reduction goal
    nn{i} = OUT{i}{1}(1,15); %budget
    oo{i} = OUT{i}{1}(1,16); %cummulative N reduction
    pp{i} = OUT{i}{1}(1,17); %cummulative P reduction
    qq{i} = OUT{i}{1}(1,18); %num of BMP1 implemented
    rr{i} = OUT{i}{1}(1,19); %num of BMP2 implemented
    ss{i} = OUT{i}{1}(1,20); %num of BMP3 implemented

    [u,y] = size(cc{i});
    if u >= m
        cc1{i} = cc{i}(1:m,:);
        ee1{i} = ee{i}(1:m,:);
        ff1{i} = ff{i}(1:m,:);
        gg1{i} = gg{i}(1:m,:);
        hh1{i} = hh{i}(1:m,:);
    else v = m-u;
        w = zeros(v,1);
        cc1{i} = cat(1,cc{i},w);
        ee1{i} = cat(1,ee{i},w);
        ff1{i} = cat(1,ff{i},w);
        gg1{i} = cat(1,gg{i},w);
        hh1{i} = cat(1,hh{i},w);
    end;
end;

%convert cell array of matricies to single matrix
ccc = cell2mat(cc1);
eee = cell2mat(ee1);
fff = cell2mat(ff1);
ggg = cell2mat(gg1);
hhh = cell2mat(hh1);
iii = cell2mat(ii);
```

```
jjj = cell2mat(jj);
kkk = cell2mat(kk);
lll = cell2mat(ll);
mmm = cell2mat(mm);
nnn = cell2mat(nn);
ooo = cell2mat(oo);
ppp = cell2mat(pp);
qqq = cell2mat(qq);
rrr = cell2mat(rr);
sss = cell2mat(ss);
ddd = sum(mean(fff,2))/sum(mean(eee,2)); %avg S reduction costs (total)
ttt = sum(mean(fff,2))/sum(mean(ggg,2)); %avg N reduction costs (total)
uuu = sum(mean(fff,2))/sum(mean(hhh,2)); %avg P reduction costs (total)

%finds mean of rows
mccc = mean(ccc,2); %area
meee = mean(eee,2); %tons of soil reduction
mfff = mean(fff,2); %total BMP cost
mvvv = mfff./meee; %avg S reduction incremental costs
mddd = cat(1,mean(ddd,2),nan(m-1,1)); %avg S reduction costs (total)
mggg = mean(ggg,2); %pounds of N reduction
mwww = mfff./mggg; %avg N reduction incremental costs
mttt = cat(1,mean(ttt,2),nan(m-1,1)); %avg N reduction costs (total)
mhhh = mean(hhh,2); %pounds of P reduction
mxxx = mfff./mhhh; %avg P reduction incremental costs
muuu = cat(1,mean(uuu,2),nan(m-1,1)); %avg P reduction costs (total)
miii = cat(1,mean(iii,2),nan(m-1,1)); %num of BMPs
mjjj = cat(1,sum(mccc),nan(m-1,1)); %total area
mkkk = cat(1,sum(meee),nan(m-1,1)); %cummulative soil reduction
mlll = cat(1,sum(mfff),nan(m-1,1)); %total BMP costs
mmmm = cat(1,mean(mmm,2),nan(m-1,1)); %soil reduction goal
mnnn = cat(1,mean(nnn,2),nan(m-1,1)); %budget
mooo = cat(1,sum(mggg),nan(m-1,1)); %cummulative N reduction
mppp = cat(1,sum(mhhh),nan(m-1,1)); %cummulative P reduction
mqqq = cat(1,mean(qqq,2),nan(m-1,1)); %num of BMP1 implemented
mrrr = cat(1,mean(rrr,2),nan(m-1,1)); %num of BMP2 implemented
msss = cat(1,mean(sss,2),nan(m-1,1)); %num of BMP3 implemented

SumOut =
cat(2,bb,mccc,mfff,meee,mvvv,mddd,mggg,mwww,mttt,mhhh,mxxx,muuu,miii,mjjj,mlll,mmmm,mnnn,
mkkk,mooo,mppp,mqqq,mrrr,msss);
SumOutcell = num2cell(SumOut);
Headings = {'#' 'Area (ac)' 'TotBMPCost' 'S_Quantity (tons)' 'AVGincremCost_S (/ton)' 'AVGred_S_Cost
(/ton)' 'N_Quantity (lbs)' 'AVGincremCost_N (/lb)'...
    'AVGred_N_Cost (/lb)' 'P_Quantity (lbs)' 'AVGincremCost_P (/lb)' 'AVGred_P_Cost (/lb)'
'TotBMPnum' 'Total Area (ac)' 'TotBMPCost'...
    'S_RedGoal (tons)' 'Budget' 'Cumm_S_Quantity (tons)' 'Cumm_N_Quantity (lbs)' 'Cumm_P_Quantity
(lbs)'...
    '# of BMP1' '# of BMP2' '#of BMP3'};

allOutput = [Headings; SumOutcell];
```

```
xlswrite('RandS_15yr_50K.xls',allOutput,1,'A1');
%end;

%--------------------------------------------------------------

%-----------------------------
%This code erases any empty sheets in an excel workbook
%Open the output xls file

excelObj = actxserver('Excel.Application');
%opens up an excel object
excelWorkbook = excelObj.workbooks.Open(OutFile);
worksheets = excelObj.sheets;
%total number of sheets in workbook
numSheets = worksheets.count;

count=1;
for j=1:numSheets
   %stores the current number of sheets in the workbook
   %this number will change if sheets are deleted
   temp = worksheets.count;

   %if there's only one sheet left, we must leave it or else
   %there will be an error.
   if (temp == 1)
      break;
   end

   %this command will only delete the sheet if it is empty
   worksheets.Item(count).Delete;

   %if a sheet was not deleted, we move on to the next one
   %by incrementing the count variable
   if (temp == worksheets.count)
      count = count + 1;
   end
end
excelWorkbook.Save;
excelWorkbook.Close(false);
excelObj.Quit;
delete(excelObj);

% Run OfficeDoc to format Excel output
% Open document in 'append' mode:
[file,status,errMsg] = officedoc('RandS_15yr_50K.xls', 'open', 'mode','append');

for z=1:1
   status = officedoc(file, 'format', 'sheet', z, 'Range', 'A1:W1', 'bold','on','WrapText',1);
   status = officedoc(file, 'format', 'sheet', z, 'Range', 'D:D,E:E,F2,H:H,I2,K:K,L2',
'NumberFormat','$#,##0.00');
```

```
    status = officedoc(file, 'format', 'sheet', z, 'Range', 'D:D,G:G,J:J,U2,V2,W2',
'NumberFormat','#,##0.00');
    status = officedoc(file, 'format', 'sheet', z, 'Range', 'C:C,O2,Q2', 'NumberFormat','$#,##0');
    status = officedoc(file, 'format', 'sheet', z, 'Range', 'B:B, M2,N2,P2,R2,S2,T2', 'NumberFormat','#,##0');
    status = officedoc(file, 'format', 'sheet', z, 'Range', 'A:W', 'ColAutoFit',1);
end

% Close the document, deleting standard sheets and releasing COM server:
status = officedoc(file, 'close', 'release',1,'delStd','off');

% Re-display document; file is no longer valid so we must use file name:
%officedoc('RandS_15yr_50K.xls', 'display');

toc
```

Sediment Baseline Assessment

Basic Information

Title:	Sediment Baseline Assessment
Project Number:	2009KS71B
Start Date:	3/1/2010
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	2nd
Research Category:	Climate and Hydrologic Processes
Focus Category:	Sediments, Water Quality, None
Descriptors:	None
Principal Investigators:	Dan Devlin, Will Boyer, Brock Emmert, Bruce McEnroe, C. Bryan Young

Publications

There are no publications.

Sediment Baseline Assessment

Project Number: 2009KS71B

Start Date: 1/1/2009

End Date: 2/29/2012

Funding Source: 104B

Focus Categories: Sediments, Water Quality

Descriptors: Sediment, Assessment, Sediment Load, Reservoir Sedimentation, Banner Creek Lake

Primary PI: Dr. Daniel. Devlin, Kansas Center for Agricultural Resources and the Environment (KCARE), Kansas State University

Other PIs: Mr. Will Boyer, KCARE, Kansas State University
Dr. Kyle Mankin, Dept. Of Biological and Agricultural Engineering, Kansas State University
Dr. Bruce McEnroe, Civil, Environmental, & Architectural Engineering, University of Kansas
Dr. C. Bryan Young, Civil, Environmental, & Architectureal Engineering, University of Kansas
Mr. Brock Emmert, The Watershed Institute, Inc.

Project Class: Research

I: Technical Report

a:

Problem Statement

This sediment baseline research plan is a comparative watershed study. Seven characteristics in each of the study watersheds were compared and contrasted to determine 1) process/setting/sources of sediment, 2) potential management measures to reduce sediment movement and transport and 3) a monitoring method to measure management impact effectiveness. The study watersheds were selected based uponavailability of existing information from previous research efforts in the candidate watersheds and presumed large differences in the range of sediment loads between them. Each study watershed is of comparative size and located within the same ecoregion inKansas.

Generally, the term ‘baseline’ in this study plan refers to the existing sediment load transported with a watershed. A target condition also exists where the sediment load in a watershed is minimized given watershed size and ecoregion in Kansas. For the purposes of this study, that target condition is defined by the smallest baseline sediment load of the study watersheds.

The seven watershed characteristics for assessment are: geomorphology, hydrology, and geology/soils, which comprise the physical setting and process portion of the baseline assessment methodology; riparian condition and land use which encompass the management opportunities in the watersheds and; and biology and chemistry which will be used to assess the

current condition and then measure movement toward the desired outcome in the streams and lakes of the watersheds.
The characterization of each of the study watersheds is intended to relate those characteristics to the sediment loads in each watershed. Ultimately, the management goal is to change the characteristics in watersheds with larger sediment loads to something that emulates the characteristics in watersheds with smaller sediment loads and use the monitoring to determine the management practice effectiveness toward that reduction.

In 2005, the Kansas Water Office (KWO) in consultation with the Watershed Restoration and Protection Strategy Workgroup developed a Sediment Management Strategy Outline that provided a summary of the sediment issues in the state that needed to be addressed prior to the development of comprehensive statewide sediment management plan. The sediment issues in that strategy outline were created to be topics for sediment research.

The intent of the research on each of those sediment issues is to enhance the knowledge and understanding of each of the issues. This is important because management and policy decisions will be made at the state level with this enhanced knowledge and understanding to ultimately improve the effectiveness of practices and programs in reducing the adverse impacts of sediment on Kansas lakes and streams. Results of the research on each sediment issue will be used to drive sound, scientifically-based management and policy decisions. Kansas Water Resource Institute (KWRI) convened a sediment conference in 2006 to discuss sediment issues in the state. Experts from all research institutions in the state were invited to attend, review and discuss the sediment issues in the Sediment
Management Strategy Outline. The result of that conference was the assignment and creation of sediment white papers (available at http://www.oznet.ksu.edu/library/Sedimentation.htm) which reviewed the current state of knowledge and identified areas where additional studies were still necessary.

In 2008, the KWRI convened a follow-up sediment conference to review the sediment white papers and initiate the production of research methodologies on three of the six sediment issues identified in the original Sediment Management Strategy Outline. The issue of identifying a baseline sediment load within various physiographic and geologic setting in Kansas was one of those three sediment issues address at that conference. Five additional meetings have been coordinated by the KWO in 2008 to continue this effort to create a Sediment Baseline Assessment Work Plan. This research work plan
represents the result of that effort.

The Baseline Sediment Assessment Workgroup selected three watersheds for the sediment baseline study ranging in drainage area size from just over 19 square miles to over 8 square miles. Two of the three study watersheds are located in the Perry Reservoir drainage area (1,117 square miles) and all three are in the Western Corn Belt Plains ecoregion of Kansas. The watersheds drain into reservoirs at the lower end of each watershed. Those lakes are Banner Creek Lake, Centralia Lake and Atchison County Lake. Previous studies and data collected at these lakes indicate a good mix of probable sediment sources and relatively wide range of sediment loads delivered to the study lakes. Bathymetric surveys to assess the current state, trend and spatial variability of sediment are scheduled for Banner Creek, Centralia Lake and Atchison

County Lakes in State Fiscal Year 2010.

<u>Objectives and Methods</u>

Part 1. Physical Setting and Process: Geomorphological Assessment

I. Channel Evolution Assessment in the Banner Creek, Centralia, and Atchison County Lake Watersheds - Bryan Young and Bruce McEnroe, KU Department of Civil, Environmental, and Architectural Engineering

This component of the Sediment Baseline Research program focuses on aerial reconnaissance of streams in the three subject watersheds (the watersheds for Atchison County Lake, Banner Creek Lake, and Centralia Lake). The objective is to identify channel evolution stage using the aerial imagery.

Helicopter videography was collected for all three watersheds in March, 2009. This video, along with digital stills, has been georeferenced and made available to other team members in a geographic information system (GIS). Digital still frames have been extracted from the video at representative locations along the streams; these stills have also been made available in the GIS.

Determination of the stage of channel evolution for each stream is underway. Each digital still has been classified for a range of geomorphic characteristics. These characteristics are being analyzed to group adjacent stream segments with similar qualities. Once stream segments have been identified, a channel evolution stage will be assigned by project personnel.

Efforts during the current reporting period (3/1/2010 – 2/28/2011) focused on a) manual interpretation of historical aerial photographs and on b) geomorphic surveys conducted by The Watershed Institute (TWI). GIS was used to digitize stream centerlines, impoundments, and impoundment watersheds for historical aerial photographs for all three watersheds. The dates for these photographs range from the 1940s through 2008. TWI performed complete geomorphic surveys at select locations in the three watersheds. A total of thirteen geomorphic surveys were conducted during the current reporting period; three more surveys are planned.

a. Publications:

Work in progress was presented at two conferences (oral presentation, no proceedings):

Shelley, John; C. Bryan Young; Bruce M. McEnroe, 2010, “Helicopter-based Videography for Channel Evolution Stage Determination,” presented at the World Environmental & Water Resources Congress 2010, Providence, Rhode Island.

Young, C. Bryan; John Shelley; Bruce M. McEnroe, 2010, “Understanding Stream

Evolution using Aerial Imagery," presented at Water and the Future of Kansas, Topeka, Kansas.

b. Information Transfer Program:

The GIS database of digital photographs and videos have been made available to the research group on the Kansas Water Office website.

c. Student Support:

This research supported three undergraduate research assistants and one graduate research assistant in the department of Civil, Environmental, and Architectural Engineering at the University of Kansas.

Consulting work on Geomorphology Surveys - Brock Emmert, Watershed Institute
TASK 1: SITE SELECTION
Use information—hydrology, litho-stratigraphy, channel evolution determination—gathered by USGS, KGS, and KUCE to help focus reach-scale geomorphology site selection. TWI would also complete a brief field reconnaissance to finalize survey sites. TWI recommends that the geomorphology sites overlap with other field investigations and sites be selected to capture the greatest variety of physical settings.
TWI recommends at least five reach-scale surveys for Banner Creek Reservoir and Atchison County Lake. For Centralia Lake, TWI recommends eight geomorphology surveys—four in each subbasin.

TASK 2: DATA COLLECTION.
TWI will survey the physical dimensions of the channel to determine the dimension, pattern, and profile of the bankfull or channel forming discharge. In addition, TWI will document streambank stability characteristics (bank angle, rooting depth and density, bank composition, bank height ratio, and bank toe protection) to rate the erosion potential within the survey reach. TWI will also note general conditions of the riparian corridor such as corridor width, density, and list the dominant species.

TWI will install monuments for monitoring streambank and streambed erosion at each site. This will validate erosion predictions from geomorphology survey.

TASK 3: DATA ANALYSIS.
TWI will use the quantitative, objective survey data to classify each stream reach according to the
Rosgen Stream Classification of Natural Rivers. For the streambank stability data, TWI will use the Bank Erodibility Hazard Index (BEHI) to rate the bank erodibility and predict an annual erosion rate. TWI will also complete the Pfankuch Stream Stability Evaluation based on field data. Finally, TWI will summarize stream stability ratings for each survey that will validate the channel evolution stage.

TASK 4: MONITORING

In order to validate erosion predictions, TWI will complete a three-year monitoring effort. At each survey, TWI will establish benchmarks for monitoring changes in the stream cross section and profile, lateral erosion, and erosion/deposition of the streambed. TWI will collect field data on a quarterly basis and provide a quarterly summary of the findings. Monitoring can also be continued (if desired) to measure the success/changes if BMP are implemented.

An economy of scale applies to this approach, making aerial videography a good candidate for use on larger watersheds in the future.

Part 2. Land Use and Riparian Assessment - Dan Devlin and Will Boyer, KCARE, KSU, and Kyle Mankin, Dept. of Biological and Agricultural Engineering, KSU.

TASK 1: Obtain and analyze existing GIS databases.
Using available GIS databases determine and map land use, land cover, and, to the extent possible, management practices on the three watersheds. These databases are available from Data Access & Support Center (DASC), USDANRCS, USDA-FSA, USDA-NASS, and USGS. Data collected will include digital orthoimagery, soils data (SSURGO), digital elevation (DEM), land use and cover, crop information, and other geo-referenced databases.

TASK 2. Verify and augment information using local experts.
Once the available GIS databases have been collected and compiled, the next task is to meet with local experts to verify, validate, and augment the data. Local personnel from Extension, NRCS, Conservation Districts, and WRAPS SLT groups will be relied upon to review the preliminary soil, land use, and best management practice information. Incorporating this local knowledge is necessary to ensure that all data that is reported is accurate and up to date. This local expert group will also be relied upon to offer their guidance and expertise in the direct observation survey, which takes place next.

TASK 3. Conduct a survey of the area, making direct observations of land use and riparian and streambank condition, and ground-truthing the information from Tasks 1 & 2. Since soil surveys were completed for most counties in Kansas in the 1970’s, more than thirty years ago, and cropland management has drastically changed during that period of time, maps need to be updated and more detail added. A watershed survey needs to be conducted to input geo-referenced field data into tablet computers on crop rotations, current conservation and tillage practices (and conditions), grazing lands conditions, and other relevant information. This will be done on a field by field basis for all crop fields and grazing lands within the watersheds.

Outputs: 1) land cover/land use map for watersheds; 2) map of elevation for watersheds; 3) acres of cropland, grazingland, and urban area, in watersheds; and 3) map of location and extent of conservation practices implemented in the watersheds, which would include terraces and waterways (and their condition), range conditions, no-tillage practices, etc.

<u>Results and Their Significance</u>.

Part 1. Physical Setting and Process: Geomorphological Assessment
I. Channel Evolution Assessment in the Banner Creek, Centralia, and Atchison County Lake Watersheds - Bryan Young, KU Department of Civil, Environmental, and Architectural Engineering

II. Consulting work on Geomorphology Surveys - Brock Emmert, Watershed Institute
TASK 1: SITE SELECTION

TASK 2: DATA COLLECTION.

TASK 3: DATA ANALYSIS.

TASK 4: MONITORING

Part 2. Land Use and Riparian Assessment - Dan Devlin and Will Boyer, Department of Agronomy, KSU, and KCARE, KSU.

TASK 1: Obtain and analyze existing GIS databases.
GIS databases were obtained to map land use, land cover, and management practices. These data were collected and used included digital orthoimagery, soils data (SSURGO), digital elevation (DEM), land use and cover and crop information. Reports containing the geographical data were distributed at two quarterly sedimentation meetings at the Kansas Water Office in Topeka.

TASK 2. Verify and augment information using local experts.
County extension agents other local experts were met with and their local knowledge was added to the databases.

TASK 3. Conducted a field by field survey of the three watersheds, making direct observations of land use, and ground-truthing the information from Tasks 1 & 2.

Outputs that have been developed and available: 1) land cover/land use maps for watersheds; 2) map of elevation for watersheds; 3) acres of cropland, grazingland, and urban area, in watersheds; and 3) maps of location and extent of conservation practices implemented in the watersheds, which included terraces and waterways (and their condition), range conditions, no-tillage practices, etc.

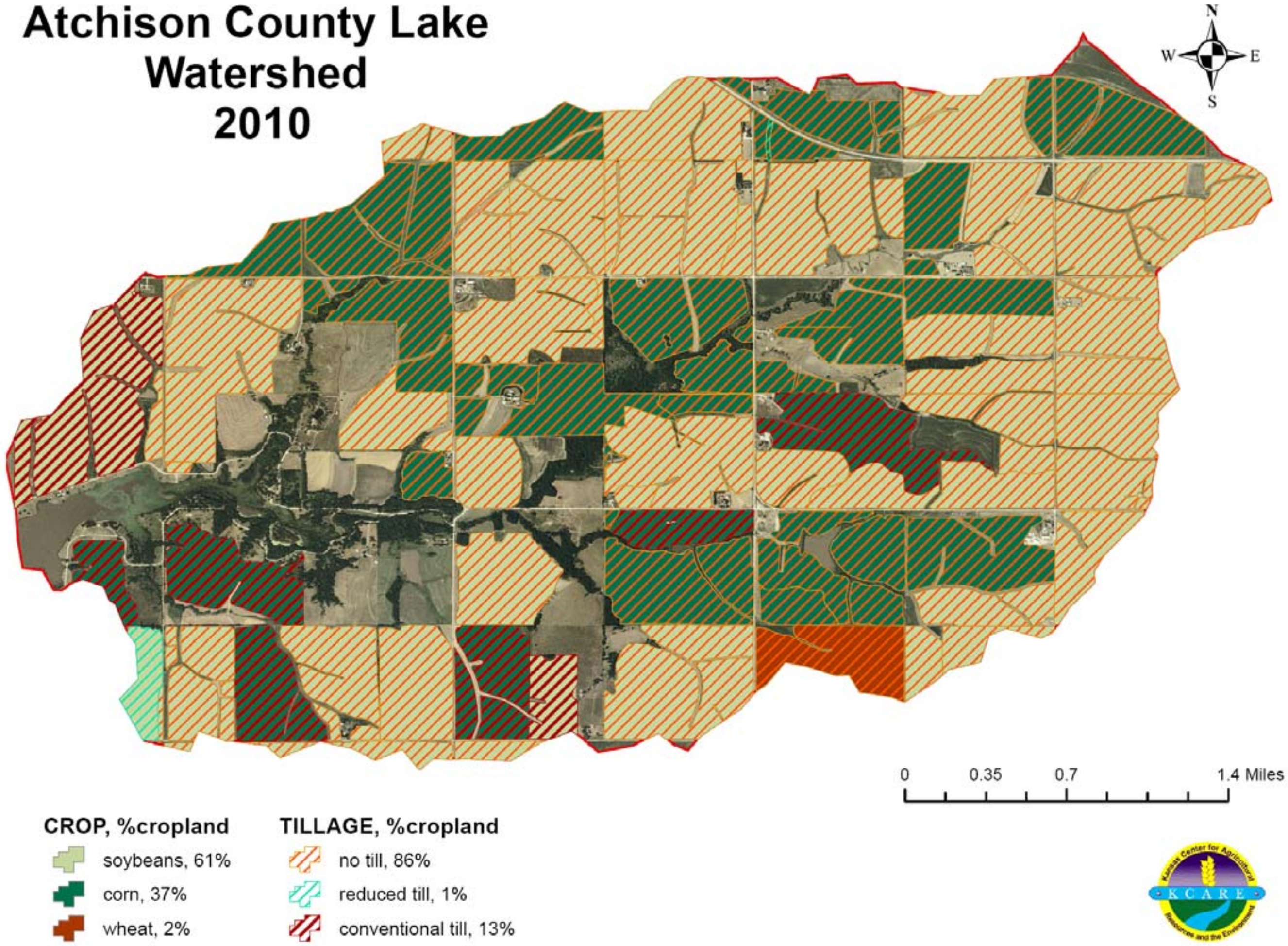
Summary of 2009 Land Use, Tillage Practices, Terraces, and Grassland in Atchison County Lake, Banner Creek Lake, and Centralia Lake

		Atchison County Lake	Banner Creek Lake	Centralia Lake
Acres in Cropland Percent of Watershed		**3,835 (66.2%)**	**459 (3.8%)**	**5,425 (60.4%)**
Percentage of the Cropland in the Watershed				
CROP	Soybeans	55.5	61.0	52.5
	Corn	44.1	16.3	33.7
	Wheat	0.3	16.7	11.2
	Other	None	None	2.7
Percentage of Cropland in the Watershed				
TILLAGE PRACTICES	No till	81.0	14.9	61.6
	Reduced till	7.8	None	11.6
	Conventional till	10.2	67.3	22.2
	Not determined	0.9	17.7	4.7
Percentage of Cropland in Watershed				
TERRACE TYPE	Terraced with waterways	41.5	52.1	71.9
	Terraced with tiles	46.8	15.7	19.3
	No terraces	3.5	26.8	2.6
	Not determined	8.1	5.4	6.1
Percentage of Cropland in Watershed				
TERRACE CONDITION	Excellent	32.1	70.9	37.9
	Average	66.8	4.1	47.5
	Needs Rebuilding	1.1	None	13.3
	Not determined	None	25.0	1.4

		Atchison County Lake	Banner Creek Lake	Centralia Lake
Acres in Grassland **Percent of Watershed**		**290** **(5.0%)**	**8,815** **(72.1%)**	**1,405** **(15.7%)**
Percentage of Grassland in Watershed				
GRASSLAND	Grazed	75.8	67.5	73.3
	Hayed	15.8	27.4	7.2
	CRP	0	0.5	13.2
	Other	8.4	4.6	6.3
Percentage of Grassland in Watershed				
GRASSLAND CONDITION	Excellent	11.0	42.4	28.9
	Fair to Good	75.9	52.3	71.1
	Poor	13.0	5.3	None

Acres in Other Uses (lakes, ponds, roads, homesteads) **Percent of Watershed**	**1,671** **(28.8%)**	**2,956** **(24.1%)**	**2,148** **(23.9%)**

Atchison County Lake Watershed 2010




Centralia Lake Watershed 2010
N
W
E
S
CROP
soybeans 48%
corn 41%
wheat 9%
other 2%
TILLAGE
no till 71%
reduced till 7%
conventional till 22%
0
0.3
0.6
1.2 Miles

Publications:

This research did not result in any publications during Year 2 of the project.

Information Transfer Program:

The GIS database of digital photographs and videos are on the Kansas Water Office website. All data and results from **Part 2. Land Use and Riparian Assessment** has been placed on the Kansas Water Office website. There were also three public presentations of the information and results to Kansas water professionals. A presentation was also given at the Water and Future of Kansas Meeting.

Student Support:

This part of the study supported one undergraduate and one graduate student.

Information Transfer Program Introduction

The KWRI is committed to transferring knowledge generated by it researchers to clientele. The KWRI uses a variety of methods. These include:

1. Annual statewide water conference held in October each year. The conference in 2010 was the 27th annual conference. The theme was Sustainable Water Resource Management: Assuring the Future. Approximately 225 people attended. Twenty-six scientific presentations were presented in plenary and concurrent sessions. Twenty-six scientific posters were presented in the poster session. For the first time, a undergraduate/graduate student poster award program was conducted to encourage student participation. Nine students participated.

2. Two statewide conferences (Febuary 4 in Hays and February 3 in Wichita, KS) were held in February in partnership with the Kansas Water Office. These conferences, Kansas Water Forums, theme was Climate and Water: Planning for the Change have a goal of presenting science and policy issues around water quality and water quantity. This past year there were 300 attendess.

3. The KWRI website, http://www.kcare.ksu.edu/p.aspx?tabid=921, is used to transfer project results and inform the public on issues and scientists on grant opportunities.

Water and the Future of Kansas Conference

Basic Information

Title:	Water and the Future of Kansas Conference
Project Number:	2008KS69B
Start Date:	3/1/2010
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	2nd
Research Category:	Not Applicable
Focus Category:	Education, None, None
Descriptors:	
Principal Investigators:	Steven M. Graham

Publications

There are no publications.

Sustainable Water Resource Management: Assuring the Future

27th Annual

Water and the Future of Kansas Conference Program

October 26, 2010
Capitol Plaza Hotel
Topeka, Kansas

Sponsored by
Kansas Water Resources Institute
Kansas Center for Agricultural Resources and the Environment
K-State Research and Extension
U.S. Geological Survey

Agenda

7 a.m.

Poster setup – Student posters must be in place by 7:30 a.m.

8 a.m.

Registration opens

8:30 a.m.

Welcome and introduction of new KCARE director

Steven Graham, KWRI Interim Director

8:40 a.m.

Sustaining Kansas Water Resources — How Are We Doing?

Mike Hayden, Secretary, Kansas Department of Wildlife and Parks

9:10 a.m.

Kansas Reservoirs as Sustainable Infrastructure

Tracy Streeter, Director, Kansas Water Office

9:40 a.m.

Break

10 a.m.

The Structure of Sustainability

Josh Svaty, Secretary of Agriculture, Kansas Department of Agriculture

10:30 a.m.

National Perspective on Water Sustainability

Karl Brooks, Regional Administrator, U.S. Environmental Protection Agency Region 7

11 a.m.

Taking a More Strategic Approach to Science Communication

Lawrie Kirk, Visiting Fellow, Center for the Public Awareness of Science, Australian National University, Canberra, Australia

11:30 a.m.

Poster viewing, WRAPs trailer viewing

Noon

Lunch

The State Economy

Duane Goossen, Secretary, Kansas Department of Administration and Director, Kansas Division of the Budget

Announcement of Student Poster Award

1:15 p.m.

Concurrent Sessions 1–4

Session 1 – The ABCs of Watershed Sedimentation

Facilitator: Andy Ziegler, U.S. Geological Survey

1:15 p.m.

Sediment Baseline Research Strategy

Chris Gnau, Kansas Water Office

1:35 p.m.

Continuous Monitoring of Suspended-sediment Transport to and from Small Impoundments in Northeast Kansas

Guy Foster, U.S. Geological Survey

1:55 p.m.

Understanding Stream Evolution using Aerial Imagery

Bryan Young, University of Kansas

2:15 p.m.

Assessing Riparian Forests in the Delaware Watershed in Relation to Sedimentation of Perry Lake

Billy Beck, Kansas Forestry Service

Session 2 – Defining Sustainability for the High Plains Aquifer

Facilitator: Susan Stover, Kansas Water Office

1:15 p.m.

Increasing Effective Action

David Barfield, Chief Engineer, Division of Water Resources Kansas Department of Agriculture

1:35 p.m.

Modeling the High Plains Aquifer in Southwest Kansas: From the Past to the Future

Gaisheng Liu, Kansas Geological Survey

1:55 p.m.

Managing the Economic Impacts of Sustainability

Bill Golden, Kansas State University

2:15 p.m.

Enhanced Groundwater Management of Special Areas of GMD4

Wayne Bossert, Groundwater Management District 4

Session 3 – Water Quality

Facilitator: Tom Stiles, Kansas Department of Health and Environment

1:15 p.m.

Kansas Reference Streams: Selection, Validation and Role in Water Quality Assessment Programs

Bob Angelo, Kansas Department of Health and Environment

1:35 p.m.

Some Observations on Water Quality Issues in Kansas: A 40-year Perspective

Don Huggins, Kansas Biological Survey

1:55 p.m.

Targeting HUC 12s with Water Samples and Windshields

Stacie Minson, Kansas State University

2:15 p.m.

The National Agenda for Improving Water Quality and the Changing Role of States

Mike Tate, Kansas Department of Health and Environment

Session 4 – Watershed Conservation Effects Assessment

Facilitator: Nathan Nelson, Kansas State University

1:15 p.m.

Citizen Leadership for Effective Watershed Protection

Lisa French, Cheney Lake Watershed, Inc.

1:35 p.m.

Fifteen Years of Water-Quality Studies in the Cheney Reservoir Watershed, Southcentral Kansas, 1996–2010

Jennifer Graham, U.S. Geological Survey

1:55 p.m.

Best Management Practices and Their Effects on Water Quality in the Cheney Lake Watershed

Dan Devlin, Kansas State University

2:15 p.m.

Economic Analysis of Crop Rotation Net Returns and the Water Quality in the Cheney Lake Watershed

Michael Langemeier, Kansas State University

2:35 p.m.

Break

2:55 p.m.

Concurrent Sessions 5—8

Session 5 – Municipal Water Sustainability

Facilitator: Brian Meier, Burns & McDonnell

2:55 p.m.

Sustainable Practices in Public Water Supply Planning

Toby Dougherty, City of Hays

3:15 p.m.

Wichita's Integrated Local Water Supply Plan

Deb Ary, City of Wichita

3:35 p.m.

A Sustainable Water Supply for Union County, Arkansas

David Oligschlaeger, Burns & McDonnell

Session 6 – Sustainable Nutrient Management

Facilitator: Mike Tate, Kansas Department of Health and Environment

2:55 p.m.

Use of Stormwater Best Management Practices to Reduce Pollution in Urban Runoff

Lee Kellenberger and Heather Schmidt, Johnson County Stormwater Management Program

3:15 p.m.

The Sustainability Umbrella of Advanced Nutrient Removal

Andy Shaw, Black and Veatch

3:35 p.m.

No Till: Does it Improve Water Quality?

Nathan Nelson, Kansas State University

Session 7 – Reservoir Sustainability

Facilitator: Earl Lewis, Kansas Water Office

2:55 p.m.

Sustaining the Corps of Engineers Reservoir System

John Grothaus, U.S. Army Corps of Engineers

3:15 p.m.

What Is the Status of Our Reservoirs?

Jerry DeNoyelles, Kansas Biological Survey

Mark Jakubauskas, Kansas Biological Survey

Session 8 – Implementing Sustainability Policies and Practices

Facilitator: Don Snethen, Kansas Center for Agricultural Resources and the Environment

2:55 p.m.

Modifying Homeowners' Lawn Irrigation Behavior to Conserve Water and Improve Water Quality

Dale Bremer, Kansas State University

3:15 p.m.

Constructed Wetland Treatment Systems: The Natural Way to Design

Dennis Haag, Burns & McDonnell

3:35 p.m.

Getting Buy-in at the 190th Air National Guard to Implement Presidential Water Conservation Directives

Mark Green, U.S. Air Force

4:00 p.m.

Adjourn

* Division of Continuing Education

* Kansas State University

* Manhattan, KS 66506

* 1-800-622-2KSU (2578)

Poster Presentations

Congratulations to Governor's Award winners in the student poster competition:

Undergraduate - Diana Restrepo-Osorio, University of Kansas

Graduate - Kira Shonkwiler Arnold, Kansas State University

Student Posters

Spatial Characteristics of Three Subwatersheds within the Middle Smoky Hill River Watershed and Their Relationship to Instream Total Suspended Solids

Dustin Fross, Department of Geosciences, Fort Hays State University

Trends in Groundwater Use in the Ogallala Region of Kansas

Paul J. Bruss, Department of Civil Engineering, Kansas State University

David Steward, Department of Civil Engineering, Kansas State University

Trends in Groundwater Use in the Ogallala Region of Kansas

Christopher Siebenmorgen, Department of Biological and Agricultural Engineering, Kansas State University

Aleksey Sheshukov and Kyle Douglas-Mankin, Department of Biological and Agricultural Engineering, Kansas State University

Assessment of Impacts of Future Climate Change Scenarios on Hydrologic Regimes in One Northeast Kansas Watershed

Christopher Siebenmorgen, Department of Biological and Agricultural Engineering, Kansas State University

Aleksey Sheshukov and Kyle Douglas-Mankin, Department of Biological and Agricultural Engineering, Kansas State University

Measuring evapotranspiration in urban irrigated lawns

Kira Shonkwiler Arnold, Department of Horticulture, Forestry, and Recreation Resources, Kansas State University

Dale Bremer, Department of Horticulture, Forestry and Recreation Resources, Kansas State University

Jay Ham, Soil and Crop Science, Colorado State University

Conserving Water and Improving Water Quality in Urban Watersheds: Survey of Residential Homeowners in Wichita, Olathe, and Salina about Lawn Irrigation

Kenton Peterson, Department of Horticulture, Forestry and Recreation Resources, Kansas State University

Dale Bremer, Cody Domenghini, Jack Fry, Steve Keely, Cathie Lavis, Rodney St. John, and Laura Moley, Department of Horticulture, Forestry, and Recreation Resources, Kansas State University

Relationship between Nutrient Cycling and Land Use in Rock Creek

Diana Restrepo-Osorio, Biology, Friends of the Kaw/University of Kansas

Tom Huntzinger, Upper Wakarusa WRAPS

New Online Course Examines Critical Water Issues Related to Irrigation in Urban Watersheds

Jacob Domenghini, Department of Horticulture, Forestry, and Recreation Resources, Kansas State University

Dale Bremer, Jack Fry, Steve Keely and Cathie Lavis, Department of Horticulture, Forestry, and Recreation Resources, Kansas State University

Assessment of Practical Saturated Thickness (PST) in Southwest Kansas GMD3 Region

Sarah R. Kreitzer

Faculty/Staff/Professional Posters

Sediment Characteristics for Reservoirs in USACE District - Kansas City

Marvin Boyer, Environmental/Planning, U. S. Army Corps of Engineers; William James, Environmental Research, U. S. Army Corps of Engineers

Targeting Streambank Instability

Anna Powell, Kansas Water Office

Developing a standardized methodology to identify existing and potential wetlands in Kansas for protection, enhancement, and restoration

Jeffery Neel, Environmental Research and Consulting, Blue Earth, LLC; Michael Houts, Kansas Applied Remote Sensing, Kansas Biological Survey; Frank Norman, Normal Ecological Consulting, LLC; John Bond, Kansas Alliance for Wetlands and Streams; Debra Baker, Kansas Water Office; Harold Klaege, Kansas Alliance for Wetlands and Streams

Ground-water Information Essential to Sustainability

Daniel Suchy, Data Resources Library, Kansas Geological Survey; Debora Stewart, Data Resources Library, Kansas Geological Survey; Dana Adkins-Heljeson, Public Outreach, Kansas Geological Survey; Brownie Wilson, Hydrogeology, Kansas Geological Survey; Kurt Look, Computer Services, Kansas Geological Survey Assessing Riparian Forests in the Delaware

Watershed and Relation to Sedimentation of Perry Lake William Beck, Department of Horticulture, Forestry, and Recreation Resources, Kansas Forestry Service, Kansas State University; Jeff Neel, Blue Earth, LLC

Denitrification 'woodchip' bioreactors for agricultural drainage water treatment

Alok Bhandari, Department of Civil Engineering, Kansas State University; Natasha Hoover, Laura Christianson, Matthew Helmers and Michelle Soupir, Agricultural and Biosystems Engineering, Iowa State University

CGP-CCEP – A Partnership Addressing Future Agricultural and Rural Community Needs Related to Climate Variability

Daniel Devlin and Charles Rice, Department of Agronomy, Kansas State University; Ben Champion, Office of the Provost, Kansas State University; John Harrington, Department of Geography, Kansas State University; Jackie Spears, College of Education, Kansas State University; Dan Kahl, Community Development, Kansas State University; Shannon Washburn, Agricultural Education, Kansas State University

Storage-volume change and sustain yield of the Equus Beds aquifer, Kansas, 1940 to 2010

Cristi Hansen and Walter Aucott, Kansas Water Science Center, U. S. Geological Survey

An Effective, Low Cost Method for Logging Groundwater Pumping

Jason Norquest and Mark Rude, Southwest Kansas Groundwater Management District No. 3

Watershed Strategy for a Sustainable Water Supply in Clinton Lake

Thomas Huntzinger, Upper Wakarusa WRAPS, Kansas Alliance for Wetlands and Streams

Kansas River Geomorphology

John Shelley, EIT, River Engineering and Restoration Section, U. S. Army Corps of Engineers, Kansas City District

STATEMAP: The National Cooperative Geologic Mapping Program in Kansas

Jon Smith and Greg Ludvigson, Stratigraphic Research, Kansas Geological Survey; William Johnson, Department of Geography, University of Kansas; Rolfe Mandel, Geoarcheology, Kansas Geological Survey; David Newell, Energy Research, Kansas Geological Survey; Robert Sawin, Stratigraphic Research, Kansas Geological Survey; Donald Whittemore, Geohydrology, Kansas Geological Survey

Groundwater Management Innovations in Kansas

Marios Sophocleous, Kansas Geological Survey, University of Kansas

Kansas Environmental Leadership Program (KELP)

Judy Willingham, Biological and Agricultural Engineering Extension, Kansas State University

Water Use in Kansas

William R. Eubank, Division of Water Resources, Kansas Department of Agriculture

Sustainable Agriculture and the SARE Program

Kerri Ebert, Kansas SARE Program, Kansas State University

Public Outreach to Reduce Stormwater Run-off in Urban and Agricultural Landscapes

Cynthia Annett, Science and Educational Outreach, Friends of the Kaw/Kansas Riverkeeper; Laura Calwell, Kansas Riverkeeper, Friends of the Kaw/Kansas Riverkeeper; Heidi Mehl, Department of Geography, Kansas State University; Ben Nasbah, Global Indigenous Nations

Studies, University of Kansas; Temashio Anderson, School of Architecture, University of New Mexico

NWS's River Forecast Centers: A History of Change

Juliann Meyer, Missouri Basin River Forecast Center, National Weather Service

USGS Summer Intern Program

None.

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	3	0	0	0	3
Masters	1	0	0	0	1
Ph.D.	1	0	0	0	1
Post-Doc.	0	0	0	0	0
Total	5	0	0	0	5

Notable Awards and Achievements

Publications from Prior Years